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HACKENSACK MEADOWLANDS AIR POLLUTION STUDY

AIR QUALITY IMPACT OF LAND USE PLANNING

Environmental Research and Technology,
Incorporated

PREPARED FOR
Environmental Protection Agency
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16. ABSTRACT

The Hackensack Meadowlands Air Pollution Study consists of a summary report and five task reports. The summary report discusses the procedures developed for considering air pollution in the planning process and the use of these procedures to evaluate four alternative land use plans for the New Jersey Hackensack Meadowlands for 1990. The task reports describe (1) the emission projection methodology and its application to the Hackensack Meadowlands; (2) the model for predicting air quality levels and its validation and calibration: (3) the evaluation and ranking of the land use plans; (4) the planning guidelines derived from the analysis of the plans; and, (5) the software system.

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PREFACE

The Hackensack Meadowlands Air Pollution Study final report consists of a summary report, five task reports, and three appendices, each bound separately. This report is the fourth of the five task reports. Its purpose is to describe the set of planning guidelines for considering air pollution in the urban and transportation planning process as derived from the analysis of land use plans for the New Jersey Hackensack Meadowlands.

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1. INTRODUCTION

1.1 Background

In response to the nearly universal recognition of air pollution as a problem which threatens human health and the quality of life, government agencies at all levels have enacted laws and undertaken programs designed to abate this problem. The majority of these efforts have dealt with the direct control of emissions from sources, especially those which are large users of fuel, through establishment of a system of regulations and enforcement procedures. Unquestionably such an approach is both necessary and highly effective.

It is equally clear, however, that such measures are often costly, difficult to enforce, and raise many other problems such as the equity of source emission control measures on various sectors of the economy and the general population.[1,2,3] It has been observed for example, that most of the existing air pollution control measures are "ad hoc" remedies applied on a piecemeal basis to specific problems without regard for long term effects. In fact it has been predicted that most of these measures may in the long term produce results counter to the desired objectives of the control measures. Regardless of the accuracy of such predictions, the important point is that most current air pollution control and abatement procedures are primarily concerned with current problems, and little effort has been devoted to examining appropriate measures for achieving long term solutions to the air pollution problem.

The degradation of air quality results from the large amounts of contaminants emitted into the atmosphere from all sectors of our rapidly expanding technological society. Air pollution is not simply the result of automobiles, industry, power plants and incinerators. Rather, in the long term it is more fundamentally related to a growing population and the resultant demands for energy, mobility, and the development of land.[4] It is the relationship between the policies, priorities, and mechanisms for satisfying these demands within the constraints of limited resources that ultimately determines the quality of our environment.

In recognition of these facts, the Federal Government has recently begun to consider long term solutions to the air pollution problem within the context of the much broader issues of total waste management, national energy policies, and national land use policies.[5,6,7,8] More specifically the Federal Government has undertaken programs of research designed to stimulate greater consideration of air pollution (as well as other environmental concerns) in the land use and transportation planning process.[9,10,11] These efforts are based on the premise that long term solutions can only be achieved through the consideration of a broad range of technical, economic, social and political factors, and that the planning process is especially well suited for undertaking the study of such long term comprehensive goals.

Although some studies have been completed and many more are underway, it is evident that the complex relationships between air quality, urban form, economic development, and social needs are not yet well understood. To date, research studies have generally focused on determining the status of air pollution concentrations in the planning process, and on attempting to provide information to urban and transportation planners to acquaint them with current air pollution technology and principles, and to indicate in rather broad terms how these principles can (and should) be applied within the planning process.

For example, the Northeastern Illinois Planning Commission Study (1964 to 1967) was one early effort to project and estimate air pollution levels associated with three alternate development plans for the 1990 time period.[12] A series of studies have been undertaken by the Argonne National Laboratories for the development of an analytic dispersion model and its application of the evaluation of the impact of abatement and control measures on air quality in Chicago. These efforts have focused largely on the relationship between air quality and the establishment of source emission zoning ordnances.[13,14,15] A study undertaken by the Regional Scientific Research Institution in 1967 investigated the implications of air pollution for optimum land use patterns.[16] A land use plan was developed through a joint study of the Health Department and the Planning Commission of Hillsborough City, Florida, an effort which focused on coordinating the role of air pollution administration with land use planning.[17]

More recently a study conducted by A. M. Voorhees and Associates reviewed the status of efforts by urban and transportation planning agencies to include air pollution in their planning activities, and published a proposed 5-year program for Government action and research programs to promote air pollution considerations in planning.[18] In addition, the study resulted in the publication of two other important documents: "A Guide for Reducing Automotive Air Pollution[19]", and "A Guide for Reducing Air Pollution Through Urban Planning[20]". These guides represent one of the first attempts to compile data and issues related to air pollution in a form for use by planners.

A large number of other studies (not all of which were government sponsored) relating air pollution and urban planning have been reported in the literature. The annotated bibliography by Pelle[21,22] represents a relatively comprehensive survey of literature published on this subject prior to 1965, and the annotated bibliography by Van Nest and Hagevik[23] represents a recent update of such literature.

Yet, in spite of these prior studies, very little has yet emerged in the way of in-depth analytical studies to provide quantitative guidelines and procedures for the analysis, evaluation, and ranking of alternative land use plans. As pointed out in the Voorhees report[20], urban planning decisions are often made without proper consideration of their air pollution consequences, primarily because: (1) planners and decision-makers lack precise knowledge of the effect which urban elements have on air pollution; (2) there are no established procedures for incorporating air pollution considerations into plan-making activities; and (3) few communities or agencies have the legal tools to enforce the land use policies necessary to deal with the air pollution problem.

In recognition of these needs the Environmental Protection Agency (EPA) and the State of New Jersey have jointly sponsored a study to initiate air pollution considerations in the development, evaluation and selection of alternative land use plans for the Hackensack Meadowlands. This study represents a part of the continuing Federal program of research to develop methodologies and procedures whereby the planner can incorporate air pollution considerations into the planning process.

A primary goal of this study has been to derive quantitative planning guidelines based on the results of the air pollution analysis of the Hackensack Meadowlands land use plans. The objective of this document is to describe the resultant set of planning guidelines.

1.2 Scope of the Planning Guidelines

Because of the complex relationships that exist between air pollution and other planning issues, it is convenient to define at the outset of this document different categories of planning guidelines in order to aid in understanding what is meant by "planning guidelines," and to delineate the limited scope of the guidelines presented in this report.

In brief we define "first order" guidelines as information which describes air quality resulting from a specified land use plan in terms of regional patterns of pollutant concentrations. Those guidelines should provide answers to such questions as:

1. What is the air pollution potential associated with the plan?
2. What are the factors influencing the levels of air pollution?
3. What happens to these levels if the factors are altered?

In particular the objective of "first order" guidelines is to provide a rational technical basis for relating regional air pollution to such factors as the mix, relative location, and intensity of land uses. Such guidelines also should describe the procedures and analytical methodologies for assessing the air quality impact at the regional scale.

We next define "second order" guidelines to be those which provide information concerning very localized or microscale air pollution impacts. Guidelines at this level of detail should indicate the effects of design characteristics of buildings, roadways, and other facilities. Such guidelines also should indicate the influence of open spaces, street patterns, and spatial arrangements of buildings. Specifically, man-made structures and local topographical features should be related to effects on wind fields, dispersion patterns, and the resultant localized pollutant concentration patterns over short distances (up to a few hundred meters) and short time periods (ranging from minutes to a few hours). Guidelines relating such microscale influences on air quality resulting from the design, spatial arrangement, and operation of specific urban elements should provide information useful to planners particularly in synthesizing urban and transportation system plans.

Finally, we define "third order" guidelines as those which provide data and procedures for assessing: (1) The relationships between air pollution and other environmental concerns (e.g., water pollution or solid waste disposal); (2) the relationships between air pollution and other planning issues (e.g., housing, employment, and social needs); (3) the relationship of air pollution to effects of direct interest (e.g., health effects, damage costs and economic impacts), and (4) the relationship between procedures for the abatement of air pollution through land use policies and the legal and institutional constraints to implementing such policies.

The guidelines presented in this document are totally devoted to describing first order relationships between air pollution and the planning process. During the course of this research it was observed that very little data and quantitative information exist, even at the most rudimentary level of detail, which relate large scale land use developments and transportation systems to regional air quality. Consequently, it is to be noted from the outset that some of the results included in these guidelines represent quantitative affirmations of conclusions and relationships generally accepted on the basis of intuition and judgment, but not stated quantitatively because of the lack of suitable analytical methodologies. Thus this research effort represents a significant initial step in deriving quantitative planning guidelines.

More specifically the guidelines described in this document have been derived based on the results of a sophisticated, detailed analytical study and comparative evaluation of four alternative comprehensive land use plans for the Hackensack Meadowlands for the 1990 time frame. Thus the resultant quantitative guidelines are somewhat dependent upon assumptions made for the Meadowlands plans, for example, assumptions concerning fuel use, centralized heating systems, lot coverage, and floor space per dwelling unit. The analytical procedures are sufficiently general to permit extension of the analysis and the results to most other situations and assumptions. The results, however, would not be applicable to regions having significant variability in topographic features and local climatology throughout the planning region.

In the following sections we present three basic elements of the first order planning guidelines. In Section 2 a summary of procedures and methodologies for incorporating air pollution considerations into the planning process is presented. This section also describes the AQUIP System, a computer-based analytical tool developed as part of this research project for undertaking detailed studies of air pollution impact from land use plans. And in recognition of the frequent need for rapid evaluation of plans without resorting to the use of a computer, a simplified technique for comparing plans in terms of total emissions is described.

Section 3 presents a summary of the characteristics of the four land use plans evaluated for the Hackensack Meadowlands, and a summary of the results of the air quality analysis which provide the quantitative basis for the derivation of planning guidelines. These results illustrate the use of the AQUIP System and the analytical procedures and methodologies for regional air quality analysis.

Finally Section 4 presents the conclusions of this study, stated in the form of guidelines to illustrate basic relationships between air quality and those planning factors which influence air quality.

2. PROCEDURES FOR CONSIDERING REGIONAL AIR POLLUTION IN THE PLANNING PROCESS

2.1 Fundamentals of Air Pollution Analysis for the Planner

This section provides basic information on air pollution analysis methods which can be employed by planners. In particular, this material addresses the following basic questions:

1. What are the criteria for decision-making on air pollution issues?
2. What pollutants must be considered by the planner?
3. What analysis methods are available to the planner for the review of air quality questions?

2.1.1 Criteria for Air Pollution Decisions by the Planner

The planner typically must consider data and criteria covering a wide range of issues such as housing, industrial and commercial facilities, transportation, open space, and environmental control in order to develop optimal land use programs. The following guidelines are suggested as basic criteria for planners in the consideration of air pollution issues.

(1.) Air pollutant concentrations must comply with appropriate standards at all locations.

Air quality standards are usually stated as maximum permissible concentrations of individual pollutants over specified sampling times. The time periods used in the definition of standards are different for the various pollutants; typical averaging times used in federal and state regulations

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are one hour, 3 hours, 8 hours, 24 hours and one year. Monthly and quarterly averages are not usually employed in air quality standards.

The Clean Air Act Amendments of 1970 require that the Administrator of the U. S. Environmental Protection Agency (EPA) promulgate standards for various air pollutants, as required to safeguard the public health and welfare. Federal ambient air quality standards for six community air pollutants (sulfur dioxide, carbon monoxide, nitrogen dioxide, particulate matter, hydrocarbons, and photochemical oxidents) were announced by the EPA Administrator on 30 April 1971,[24] and the air pollution control agencies of all 50 states are required to bring about compliance with these standards as soon as possible, and in no case later than 1977. In some cases, individual states have air quality standards which are more stringent than the federal standards. A wide range of other specified pollutants are also subject to control at the federal and the state levels. These include particulate material such as asbestos fibers and lead compounds, and several toxic gases.

Because of the requirement to attain the federal air quality standards by 1977 (and, in some cases, state standards at earlier dates) planners will be required to examine the expected air pollution impact of proposed land use programs. In most cases, the state air pollution control agency will be responsible for the final review and approval of land use plans relative to expected air pollution impact.

(2.) Planners should attempt to minimize air pollution concentrations in the areas where population density will be high.

An alternative form of this principle may also be stated: Planners should locate residential and occupational land use areas in regions where relatively low concentrations of pollutants are expected.

This principle applies to cases where all the applicable air quality standards will already be met. Locating population centers in regions of low concentrations will provide an additional margin of safety relative to health effects, and will provide a more pleasing air environment for the population.

It must be noted, of course, that some types of air pollution are directly related to population density. These include motor vehicle emissions resulting from local transportation, and emissions associated with onsite heating requirements. Therefore it is not possible to locate a population center in a low concentration area without causing some local increase in pollutant concentrations.

(3.) Planners should favor maximum reduction of concentrations at all locations.

The specification of maximum emission controls is primarily an engineering and regulatory question. However, planners designing new land use patterns should favor the imposition of such controls for all new facilities. Conversely, new facilities should not be permitted to use inferior emission controls with the expectation that local atmospheric dispersion will be adequate to assure compliance with the pollutant concentration standards. Instead, "good" air quality (i.e., air quality better than that required by the standards) should be preserved at all possible locations.

2.1.2 Pollutants of Interest to the Planner

Generally, the planner must be concerned with all pollutants which are potentially damaging to public health, or to vegetation, animals and inanimate material. Also, the planner must consider pollutants which reduce the public enjoyment of life and property, even when no specific regulatory standards are being violated. These pollutants include odorous compounds, substances which are irritants to the eyes and other tissues, and substances which reduce visibility through the atmosphere. Specifically, planners must investigate pollutants for which ambient air quality standards have been promulgated, and any other toxic substances which might be released to the atmosphere as a result of specific activities within the planning area.

Table 1 lists the community air pollutants for which ambient air quality standards have been promulgated by EPA[24]. It is important to note the major differences in sources among the pollutants. Transportation systems (principally involving motor vehicles) are responsible for the great majority of CO emissions, about half the NO_x and HC emissions, and a significant portion of certain particulate emissions such as lead. However, transportation sources are not responsible for any significant portion of SO_2 emissions or total particulate emissions. Therefore, transportation system decisions can have major impacts upon CO, NO_x, and HC concentration patterns, but little effect upon SO_2 and particulate patterns. Decisions on the location of stationary sources can have a major impact on SO_2 patterns, but no appreciable impact on CO.

Toxic substances other than the principal community air pollutants (for example, asbestos, beryllium and mercury) are usually emitted from specific, identified industrial sources. For these pollutants, planners should consider the expected emission rates, and should attempt to place sources of such pollutants at safe distances relative to residential, commercial and public areas.

TABLE 1

PRINCIPAL SOURCES OF THE COMMUNITY AIR POLLUTANTS IN URBAN AREAS

Pollutant	Principal Sources *	Comments
Sulfur Dioxide (SO_2)	Electric power generation (40%) Space heating (30%) Other combustion of fuels in industrial processes (30%)	Not related to transportation
Carbon Monoxide (CO)	Motor vehicles (90%) Other combustion sources (10%)	Maximum CO concentrations occur adjacent to high-density roadways.
Nitrogen Oxides (NO_X)	Stationary source combustion (50%) Motor vehicles (50%)	No NO_X removal processes for stationary source effluents are available.
Total Suspended Particulates (TSP)	Many sources, including combustion (stationary & mobile), crushing & grinding operations, & natural sources.	Particulate concentration measurements are dependent upon particle size distribution.
Hydrocarbons (HC)	Motor vehicles (60%) Industrial process & evaporative losses from storage facilities (40%)	Typical ambient concentrations of hydrocarbons are not considered dangerous to public health.
Oxidants (primarily Ozone)	Produced by action of sunlight on HC and NO_X compounds in the atmosphere.	The EPA strategy for control of oxidants is the control of HC concentrations.

*The percentage figures represent approximate contributions for the sources mentioned in middle latitude urban areas. For more specific information, refer to the annual reports of the Council on Environmental Quality.

2.1.3 Analysis Methods: Transport and Dispersion of Pollutants in the Atmosphere

The basic method for the prediction of future air pollution concentration levels expected to result from the implementation of a land use plan is the use of an atmospheric dispersion model. As illustrated schematically in Figure 1, such models translate data on emission patterns into patterns of expected concentrations for given time frames. In addition to emissions data, dispersion models require local meteorological and topographic data in order to make estimates of concentration patterns. Also, local air quality measurements are needed to evaluate model performance, and to specify confidence limits for the model results.

The air quality data usually desired from model projections are estimates of ground level concentrations of pollutants. Greatest emphasis is placed on calculating pollutant concentrations at locations especially sensitive to pollutant effects; for example, locations of high population density, or locations of high recreational or economic (e.g., cash crop) value.

A complete atmospheric dispersion model would treat four phenomena affecting pollutants in the atmosphere:

1. Transport of Pollutants - Transport occurs along the direction of the local wind and is determined by weather patterns, modified by local terrain.

2. Dispersion of Pollutants - Eddy motions in the atmosphere are primarily responsible for reducing the concentrations of pollutants after their introduction to the atmosphere.

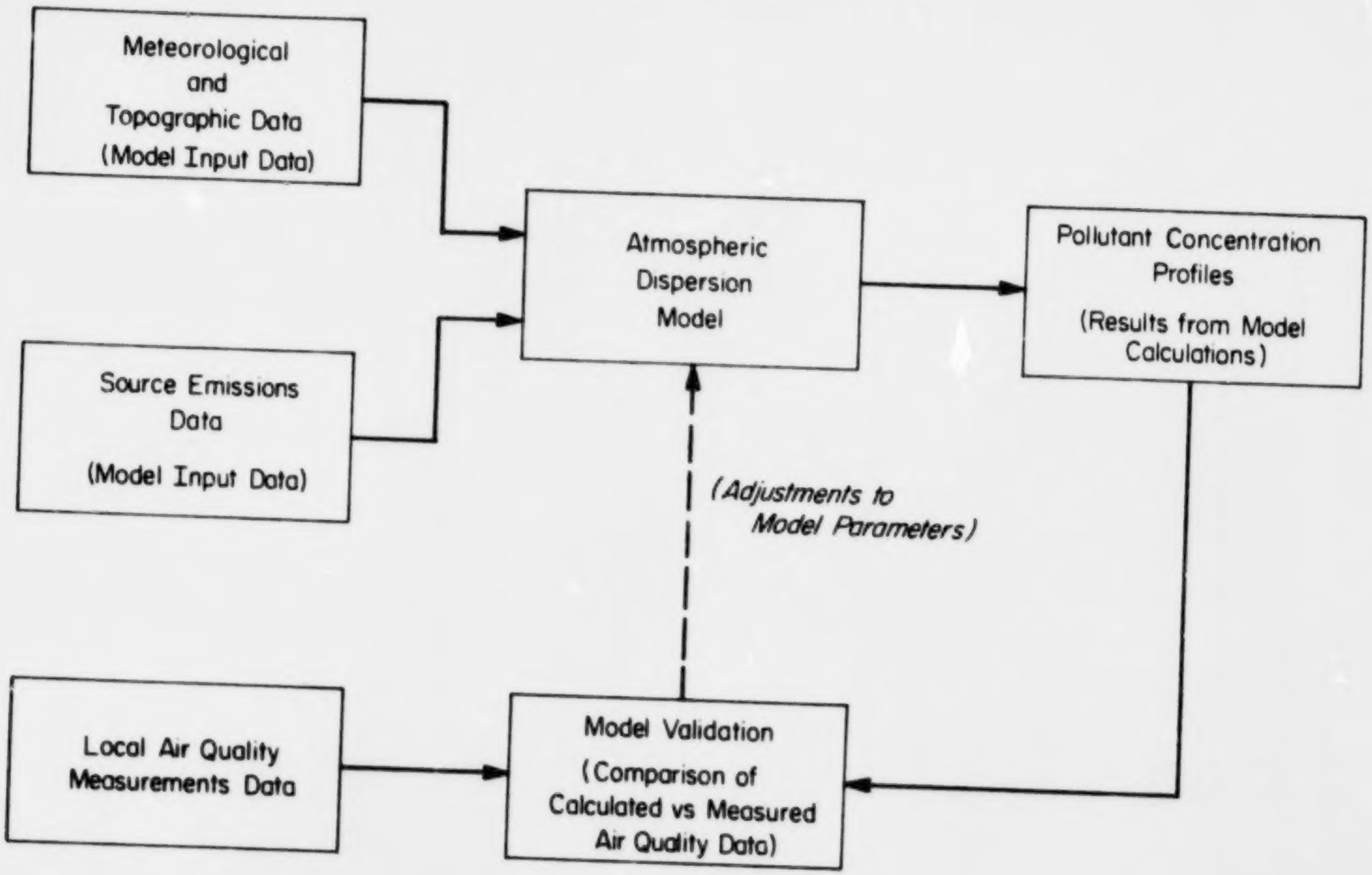
Meteorological
and
Topographic Data
(Model Input Data)
Source Emissions
Data
(Model Input Data)
Local Air Quality
Measurements Data
Atmospheric
Dispersion
Model
(Adjustments to
Model Parameters)
Model Validation
(Comparison of
Calculated vs Measured
Air Quality Data)
Pollutant Concentration
Profiles
(Results from Model
Calculations)

Figure 1 Schematic Representation of the Role of Atmospheric Dispersion Models in the Preparation of Air Quality Estimates

3. Transformation of Pollutants - Transformation processes include physical and chemical changes, and photochemical changes.

4. Removal of Pollutants - Removal processes include fallout, impaction and absorption on surfaces, and rainout.

At the present time, most dispersion models treat the first two phenomena only (transport and dispersion). Some models take account of transformation and removal by use of a "half-life" for the pollutants, but these models generally have not yet been well documented.

The simpler models require four types of meteorological data in order to compute estimated concentration patterns. These are:

1. Wind Speed - Determines "ventilation", or initial dilution of the pollution concentration.

2. Wind Direction - Determines direction of transport. (Most models assume wind direction is unchanged throughout the region of interest.)

3. Atmospheric Stability - Determines the rate of mixing and dilution of pollutants after introduction to the atmosphere.

4. Depth of Mixing Region (sometimes called "inversion height) - Determines maximum vertical extent of pollutant spread. (For major urban areas the mixing depth is a principal determinant of ground level concentrations.)

The time scales employed in model calculations carried out for planning purposes are frequently determined by the averaging times stated in the applicable air quality standards. In the averaging mode, the model weights the concentrations for each meteorological condition by the relative frequency of occurrence of each condition. However, sometimes model calculations are prepared for cyclical phenomena (e.g., daily or seasonal variability) related to variability in emission patterns and/or in meteorological conditions. Also, model calculations are sometimes carried out for "instantaneous" conditions (i.e., concentration profiles for a specified set of meteorological conditions). This approach is often used to calculate "worst case" conditions.

The atmospheric dispersion model also requires emissions input data. A well-developed dispersion model (such as the ERT/MARTIK model) will permit the planner to group emissions data according to standard geometric configurations. For example, the following three source types can be used to represent emissions from different types of activities:

1. Point Sources - Used to represent the major, identifiable sources within the region of interest; for example, electric generating stations and major industries.

2. Line Sources - Used to represent emissions from motor vehicles along principal highways, and emissions from aircraft.

3. Area Sources - Used to represent the large number of small, individual sources within a region (i.e., sources which are too small to treat individually, such as emissions from heating plants in residences and small buildings, and from vehicles on small roads within a transportation network).

The accuracy of model calculations should also be of concern to the planner. Generally, models are more accurate for the prediction of regional average concentration patterns (for example, over a 100 km^2 region) than for the prediction of "microscale" patterns (for example, within a 1 km^2 region). Also, model predictions will be more accurate when good emissions data and meteorological data are available, and when the terrain in the region of interest is relatively smooth.

2.2 General Methodology for Plan Evaluation and Ranking

The objective of this section is to provide an outline of procedures for carrying out the analyses and evaluations of land use plans in terms of air quality considerations. The material describes first an overview of the procedures and second a discussion of specific quantitative measures of impact for plan evaluation and ranking. (The material presented in this section is described in more detail in the Task 3 Final Report.)

2.2.1 Overview of Air Quality Analysis Methodologies

The methodology developed in this study to permit planners to incorporate air pollution considerations within the planning process consists generally of a set of procedures for collecting, processing and interpreting land use and other input data; a set of procedures for generating air quality information from the input data; and a set of procedures for the evaluation and ranking of alternative land use plans. This combination of methodologies, procedures and analytical tools represents a system for the analysis of air pollution which has been designated as the AQUIP System (Air Quality for Urban and Industrial Planning).

The AQUIP System is a computer-oriented set of procedures involving the planner in an interative cycle of plan evaluation and modification consisting of the following basic steps (as illustrated schematically in Figure 2).

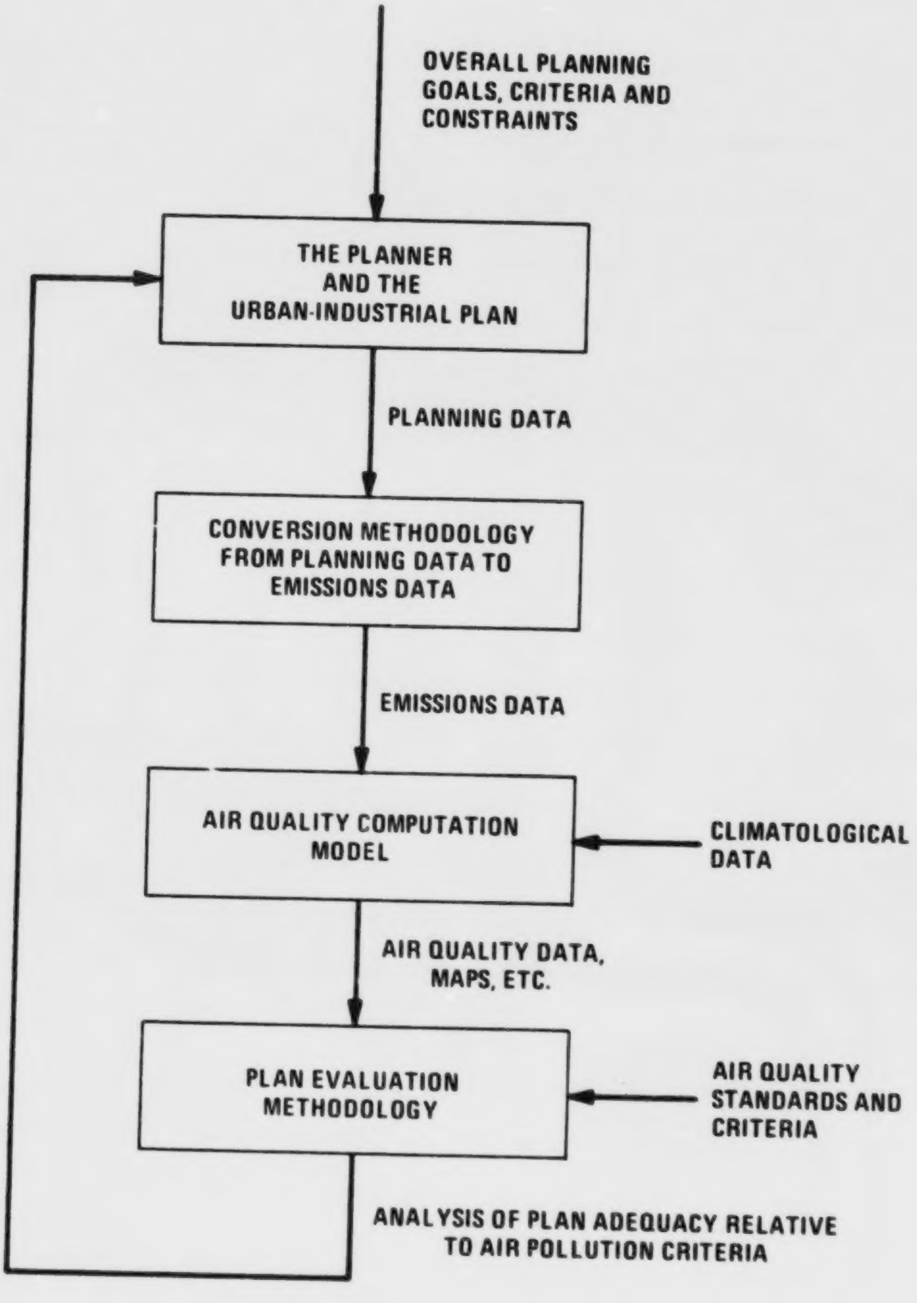
OVERALL PLANNING GOALS, CRITERIA AND CONSTRAINTS
THE PLANNER AND THE URBAN-INDUSTRIAL PLAN
PLANNING DATA
CONVERSION METHODOLOGY FROM PLANNING DATA TO EMISSIONS DATA
EMISSIONS DATA
AIR QUALITY COMPUTATION MODEL
CLIMATOLOGICAL DATA
AIR QUALITY DATA, MAPS, ETC.
PLAN EVALUATION METHODOLOGY
AIR QUALITY STANDARDS AND CRITERIA
ANALYSIS OF PLAN ADEQUACY RELATIVE TO AIR POLLUTION CRITERIA

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Figure 2 The AQUIP System Conceptual Design

1. The preparation of input data descriptive of the land use or transportation plan.

2. The conversion of this data into pollutant emissions data.

3. The prediction and display of mean ambient pollutant concentrations within the area of interest.

4. The evaluation and ranking of the plan with respect to other plans through analysis of air quality contours and the computation of quantitative measures of impact.

5. The subsequent modification of the plan or the input data and the repetition of the process.

Of these five steps the first and last require the direct involvement of the planner to specify and manipulate planning data, to assess the degree to which a plan satisfies the planning objectives and constraints, and to specify changes to the plan as deemed necessary. The remaining steps involve directly the use of computer-based models and data management programs to perform the required air quality projections and data calculations.

The procedures for the analysis of air quality associated with land use plans are based principally on the evaluation and ranking of specified alternative land use plans in terms of impact on air quality on a region-wide geographic scale and in terms of annual and seasonal average pollutant concentrations. The evaluation of air quality for a plan involves the analysis of four items:

1. The degree of compliance with ambient air quality standards.

2. The degree of impact on regional levels of air quality.

3. The degree of impact on specific receptors or land use categories which are especially sensitive to the effects of pollutants.

4. The indication of ways to modify plans to improve air quality.

Procedures for examining compliance with air quality standards require the calculation of projected air quality contours over the planning region. Maximum values of predicted air quality levels are then compared with the appropriate ambient air quality standards.

Procedures for examining the impact of land use plans on regional air quality involve first the examination of spatial patterns of air quality and secondly the calculation of quantitative measures of impact for each pollutant. The examination of the isopleth contours of pollutant concentrations over the planning region indicates the location of regions of low and high pollutant concentrations and also permits the visual examination of the influence of land use types and the relative location and intensity of land use activities on the air quality contours. The calculation of impact measures permits the quantitative assessment of the impact of alternative plans on regional air quality in terms of parameters that permit the comparative evaluation and ranking of alternative plans.

An especially important aspect of the analysis and evaluation of land use plans is the analysis of the impact of air pollution levels on specific high-risk receptors and land use categories. Procedures for such analyses include both the examination of the location of critical receptors relative to air quality contours and the calculation of quantitative measures of impact.

Procedures for plan modification using the AQUIP System consist of general guidelines based on the tabulation of annual emissions per acre for different land use categories analyzed for the Hackensack Meadowlands. Such data are used to identify land use categories which, when relocated within a plan, produce significant changes in regional air quality levels and contours, and correspondingly to identify land use categories which can be relocated within the plan without any substantial impact on regional air quality concentration levels or patterns.

2.2.2 Methodology for Plan Evaluation

Plan evaluation is defined as the analysis and interpretation of air pollution impact for a single plan and/or comparison of plans on the basis of single pollutants. The basic methodology for plan evaluation consists of procedures for the analysis of air quality on a regional scale and for the analysis of impact on specific land uses and critical receptors through quantitative measures of impact and through graphical displays of the spatial distribution of air quality contours. The essential steps in these procedures consist of:

1. The calculation and comparison of pollutant concentration levels with ambient air quality standards.
2. The correlation of air quality contours and concentration levels with specific land use categories, their relative location, and intensity of use.
3. The calculation of impact measures as defined in terms of regional air quality and in terms of impact on specific receptors.
4. The calculation and display of supplementary air quality or land use data; for example, the calculation of additional impact measures, or the display of the location of critical receptors.

The first step in the plan evaluation is the calculation of air quality data; for example, the ratio of pollutant concentrations to ambient air quality standards at points within the planning region. Examination of isopleth contours of this ratio within the planning region thus indicates the location and area of regions which exceed standards, and the amount by which standards are exceeded for each pollutant. (The specific steps for obtaining air quality and land use data, and for generating contour maps and tabular data using the AQUIP System are discussed in detail in the Task 5 Report, which describes the computer programs, their required inputs, the resultant outputs, and procedures for using these programs.)

The second step in the evaluation of land use and transportation plans is the calculation and analysis of quantitative measures of impact on regional air quality and specific receptors. In general, the impact measure must be related to a specific plan, to a specific receptor or land use category within the plan, and to a specific pollutant. Thus the impact parameter (IP) is a function of three variables: the plan, the receptor and the pollutant.

In this study the impact parameters which were found to be most useful and meaningful in plan evaluation were: (1) measures of integrated receptor exposure, and (2) measures of average receptor exposure. The integrated receptor exposure for a given plan is calculated by superimposing an arbitrary grid system on the planning region, forming the product of the number of receptors per grid cell times the pollutant concentration within the grid cell, then summing this product over all grid cells within the planning region. The general formula for the integrated receptor exposure impact parameter is

$$IP(j,k,l)_{ire} = \sum_{i} R_i(k,l)C_i(j,k) \qquad (2\text{-}1)$$

where

IP (j,k,l) = impact parameter for pollutant j, plan k, and receptor l

R_i (k,l) = number of receptors (or amount of land use area) in cell i for plan k and receptor l

C_i (j,k) = mean predicted ambient concentration within grid cell i for pollutant j and plan k

j = specified pollutant

k = specified plan

l = specified receptor or land use category

i = i^{th} grid cell within the planning region

ire = designation for integrated receptor exposure

This impact parameter has units of number of receptors times pollutant concentration, and clearly is an indicator of the cumulative value of receptor exposure within the plan. Since this impact measure is sensitive both to the number of receptors and to concentration levels, it is likewise clear that the impact measure will be higher when larger numbers of receptors are exposed, just as it will be higher when higher concentrations exist. It is to be noted also that this exposure is based upon the calculation of the mean annual concentrations. Thus the exposure represents the mean concentration to which a receptor is exposed at any instant in time. The important distinction is that this impact measure is based on exposure rather than dosage, which can only be inferred based on an assumed time duration of exposure.

The second impact parameter, the average receptor exposure is calculated from the integrated exposure impact parameter simply by dividing the resultant integrated exposure by the total number of receptors within the plan. Thus the units of the average exposure impact parameter are units of concentration. However, it is to be noted that this impact parameter represents the average pollutant concentration only within those regions of the plan where receptors are located since exposures are zero in regions of the plan where no receptors exist.

The choice of specific receptors or land uses for use in plan evaluation can be arbitrary and is largely a matter of judgment on the part of the planner and should reflect those issues which he considers most important. In the Meadowlands study the land use categories and receptors examined were: total land area of the planning region; population; students; residential land area; open space land area; and a combination of commercial and industrial land area.

An impact parameter based on total land area represents a good measure of impact on regional air quality. Since the total area of the planning region is fixed, the integrated and average exposure impact parameters differ only by a constant factor and thus both are representative of the mean pollutant concentration throughout the entire planning region.

Impact parameters based on population and student receptors are of interest in terms of health effects. Students, especially those in elementary grades, represent receptors highly sensitive to the effects of pollutants. An impact parameter based on hospitals and nursing homes is also of interest since the elderly and the ill are considered to be high-risk receptors, but was not included in the Meadowlands analysis due to the lack of information on this class of receptors from the given land use data.

An impact parameter based on residential land area is of interest since it is most representative of the basic conditions for which the ambient air quality standards were established; namely, areas where the general public has a high degree of access and high probability of long-term exposures. Residential area is of concern in terms of effects on health, plant life, materials and aesthetics.

An impact parameter based on open space is of interest because of the special nature of this land use category. Open space typically denotes parks, wooded areas, recreation areas, playgrounds, and open water. The general public usually has free access to such areas, although time exposures within these areas may be somewhat limited. Thus there is some concern for aesthetics and for health effects on both human and wildlife populations. Of greatest concern, however, is the exposure of plant life to pollutants.

Commercial and industrial areas are of interest since they include such areas as shopping centers, roadways, and pedestrian malls, where the general public does have free access, although usually for short time periods. Such areas also have large numbers of working personnel, although applicable industrial hygiene health and safety standards typically are much less stringent than ambient air quality standards.

From this large (and nonexhaustive) number of receptors, it is clear that selecting impact parameters most appropriate to the evaluation of a plan is a matter of judgment in terms of the specific plan and circumstances. In the analysis of the Hackensack Meadowlands plans, the integrated total area exposure was examined as a measure of regional air quality levels, and the average population exposure was examined as the principal measure of impact on critical receptors.

There is no limit to the number of correlations and impact measures that can be defined and applied to the evaluation of land use and transportation plans. The impact measures described above for use in the Meadowlands air pollution study are obvious choices and are easily generated from the AQUIP System using readily available air quality and land use data. However, the AQUIP System allows a significant amount of flexibility in defining and calculating other measures of impact and in specifying air quality criteria other than ambient air quality standards.

Other useful analytic procedures to aid in plan evaluation include: (1) The calculation of sensitivities of air quality (or impact parameters) to changes in land use type, location, or intensity; (2) the graphical display of the location and intensities of land uses within the planning region; and (3) the creation of yet other data sets, such as additional correlations between air quality and land use data, which can be displayed graphically.

As practical working procedures for the plan evaluation, it is convenient to construct a plastic overlay showing the boundaries, rivers, major roads, and outlines of land use categories for each plan. This overlay can be made at the same scale as the computer graphic outputs. As a result the single land use map can be overlaid onto the dozens of air quality contour maps and impact parameter spatial distribution maps. For reference and correlation work it is also useful to develop a color photograph of the plan itself at the same scale as the computer graphic air quality maps.

2.2.3 Methodology for Plan Ranking

The specific requirements for the quantitative ranking of alternative land use plans differ slightly from the requirements for the analysis and evaluation of plans. The basic need for plan ranking is to generate a single number or ranking index which can be calculated for each plan to permit the relative ranking of the plans. This ranking index may be associated with the impact of a single pollutant, thereby allowing a pollutant by pollutant comparison and ranking, or may be associated with the combined impact of all pollutants (i.e., a multipollutant air quality index).

Although it is required that the ranking methodology be based on a formula in order to permit the ranking to be based on quantitative criteria precisely stated in objective terms, it is also clear that no ranking scheme nor index is unique or absolute. In fact it is desired that the ranking scheme be sufficiently flexible to accommodate the subjective values of the planner and his particular circumstances in formulating the ranking index, and it is required that the results of the ranking methodology given reasonable agreement with known facts and the intuitive judgment of the planner.

Of the many concepts for multipollutant air quality indices described in the literature, only a few were considered to be applicable to the ranking of land use plans. More specifically, those considered to be suitable can be represented by the following general formula which combines the weighted contribution of the different pollutants:

$$RI(k,l) = \sum_{j} WF(j)\ IP(j,k,l) \qquad (2\text{-}2)$$

where

RI(k,l) = ranking index for plan k and receptor l

WF(j) = weighting factor for pollutant j

IP(j,k,l) = impact parameter for pollutant j, plan k, and receptor l

j = specified pollutant

k = specified plan

l = specified receptor of land use category

This ranking index depends on the initial selection of an impact parameter of the type discussed in the previous section (for example, average population exposure or integrated total area exposure). Such indices thus have the capability of incorporating effects on specific receptors. Other forms for both the ranking index and the impact parameter were considered (particularly power law formulas), but were rejected since they complicated the ranking index without contributing to the meaningfulness of the results.

Three specific ranking schemes were examined in detail to determine their suitability as a ranking index, and all were considered to be meaningful and useful in the ranking of alternative land use plans. The three schemes are designated as:

1. The Relative Ratio Ranking Index
2. The Pindex Ranking Index
3. The Normalized Impact Parameter Ranking Index

These ranking schemes differ only in the form of the weighting function (i.e., how to combine the impact parameters for different pollutants). The characteristic formulas for the weighting functions for each of these ranking indices are listed in Table 2 and sample calculations of each index are illustrated in Table 3.

The first scheme, the Relative Ratio Ranking Index, is an especially good procedure for comparing plans on a pollutant by pollutant basis and was, in fact, used for such an analysis of the Meadowlands plans. It gives not only the relative rank of plans, but also an indication of the percent variation between plans in air quality as based on the specific impact parameter under consideration.

The second ranking index is based on the work of Babcock[25,26] and hence is designated as Pindex, although the formula for the current plan ranking

TABLE 2

ALTERNATIVE FORMS CONSIDERED FOR A PLAN RANKING INDEX

Ranking Index(1)	Weighting Factor
1. Relative Ratio(2)	$\frac{1}{n}\left[\frac{1}{\min\limits_{k} IP\ (j,k,l)}\right]$
2. Pindex(3)	$\frac{1}{n}\left[\frac{1}{AAQS\ (j)}\right]$
3. Normalized Impact Parameter(4)	$\frac{1}{n}\left[\frac{1}{\underset{k}{\mathrm{avg}}\ IP\ (j,k,l)}\right]$

(1) $RI\ (k,l) = \sum\limits_{j} WF\ (j)\ \ IP\ \ (j,k,l)$

where

$RI(k,l)$ = ranking index for plan k and receptor l

$WF(j)$ = weighting factor for pollutant j

$IP(j,k,l)$ = impact parameter for pollutant j, plan k, and receptor l

j = pollutant

k = plan

l = receptor or land use category

n = number of pollutants

(2) $\min\limits_{k} IP$ = minimum value of the impact parameters calculated for the plans (for a given pollutant and a given receptor).

(3) $AAQS(j)$ = mean annual ambient air quality standard (or extrapolated equivalent) for pollutant j.

(4) $\underset{k}{\mathrm{avg}}\ IP$ = average value of the impact parameters calculated for the plans (for a given pollutant and a given receptor).

TABLE 3

SAMPLE CALCULATIONS FOR RANKING INDICES

Matrix Element	Matrix				Ranking Index
	Plan	Pollutant			
		A	B	C	
Impact parameters	1	1	20	4	--
	2	10	15	2	--
	3	16	25	3	--
Weighting Factors for:					
Relative Ratio (based on min IP)	--	1/1	1/15	1/2	--
Pindex (based on AAQS)	--	1/20	1/5	1/5	--
Normalized IP (based on avg IP)	--	1/9	1/20	1/3	--
Relative Ratio weighted impact parameters	1	1.0	1.33	2.0	4.33/3=1.44
	2	10.0	1.00	1.0	12.00/3=4.00
	3	16.0	1.67	1.5	19.17/3=6.39
Pindex weighted impact parameters	1	0.05	4.0	0.8	4.85/3=1.62
	2	0.50	3.0	0.4	3.90/3=1.30
	3	0.80	5.0	0.6	6.40/3=2.13
Normalized Impact Parameter weighted impact parameters	1	0.11	1.00	1.33	1.44/3=0.48
	2	1.11	0.75	0.67	2.53/3=0.84
	3	1.78	1.25	1.00	4.03/3=1.34

Numbers in this table are hypothetical.

index is somewhat more generalized than that originally proposed by Babcock for an index of total air quality. Since the weighting factor for each pollutant impact parameter is formed by taking the reciprocal of the mean annual ambient air quality standard (or extrapolated equivalent) for that pollutant, the Pindex Ranking Index has the especially good feature that it relates the impact to an absolute basis or criteria; namely, air quality standards. Thus, the Pindex Ranking Index bears some relation to an established basis and hence at least some intuitive feeling for the meaning of different magnitudes of the index can be established.

The third scheme, the Normalized Impact Parameter Ranking Index, was devised as a compromise between the other two indices. This ranking index has the significant advantage that it overcomes problems encountered in the use of the other two ranking indices (illustrated in the sample calculations in Table 3), while preserving most of their advantageous features.

On the basis of the relative merits of these three ranking indices, the Normalized Impact Parameter Ranking Index was selected for use in ranking the alternative plans for the Hackensack Meadowlands, and is recommended for general use in ranking land use plans.

The specific procedures for ranking alternative land use plans include the following steps:

1. Select or define the measure of impact (impact parameter) of interest to serve as the basis for the evaluation.
2. Calculate the quantitative measure of impact for each plan and each pollutant. (This can be done either by hand calculations based on the air quality and land use data generated previously

from the AQUIP System for the plan evaluation or can be programmed and calculated directly by the AQUIP System.)

3. Tabulate the results of the calculations of the impact parameter for each plan and each pollutant. (It is to be noted that no maps result since the data has no inherent spatial distribution characteristics.)

4. Examine the ranking of plans on a pollutant by pollutant basis. (To do this, the impact parameter data tabulated above can be used to calculate for each plan the Relative Ratio ranking index as described above, showing both the relative rank of plans and the percent variation in air quality among plans for the given pollutant.)

5. Examine the ranking of plans on the basis of the Normalized Impact Parameter Ranking Index for the combination of pollutants. (This can be done by calculating values for the ranking index for each choice of impact parameter either manually or with the AQUIP System. The resultant values of the index for each plan form the numerical ranking of the alternative land use plans.)

6. Repeat the procedure for calculating and ranking plans on the basis of combined pollutants for different impact parameters in order to determine whether different impact parameters cause the ranking of plans to change.

As an optional step, plans may be ranked based on the calculation and evaluation of other indices (for example, Land Use/Air Quality Compatibility Scores as described in the Task 3 report). Although such additional indices were not used for plan ranking in the Meadowlands study, such results were used to provide added insight into the evaluation and ranking of plans.

2.3 Operational Features of the AQUIP System Software

The Air Quality for Urban and Industrial Planning System (AQUIP) represents a set of techniques, methodologies, data sets and software components which permit urban and transportation planners to evaluate land use plans on the basis of air pollution considerations. The nature of the AQUIP System as a set of procedures for plan evaluation was described in the previous section and was represented schematically in Figure 2. The objective of this section is to describe in brief the software components of the AQUIP System which provide the analytical tools necessary to undertake the air pollution impact of land use plans. (The specific techniques and methodologies for emissions projection, air quality prediction, and plan evaluation are described in detail in Task Reports 1, 2, and 3, respectively. The detailed description of the design, use and maintenance of the AQUIP System software is given in the Task 5 Report.)

2.3.1 Overview of the AQUIP System Software

The AQUIP software system makes use of input data sets and model parameter data sets, performs computations using four basic computer programs, and provides tabular and graphical outputs of the results. The logical relationships among these elements of the software system are shown in the summary flow chart of Figure 3. Data sets are shown as rectangles, computation steps as circles, and printed output as document symbols. In addition, each element is identified by a code made up of a generic letter followed by a number. The letter prefixes and their meanings are:

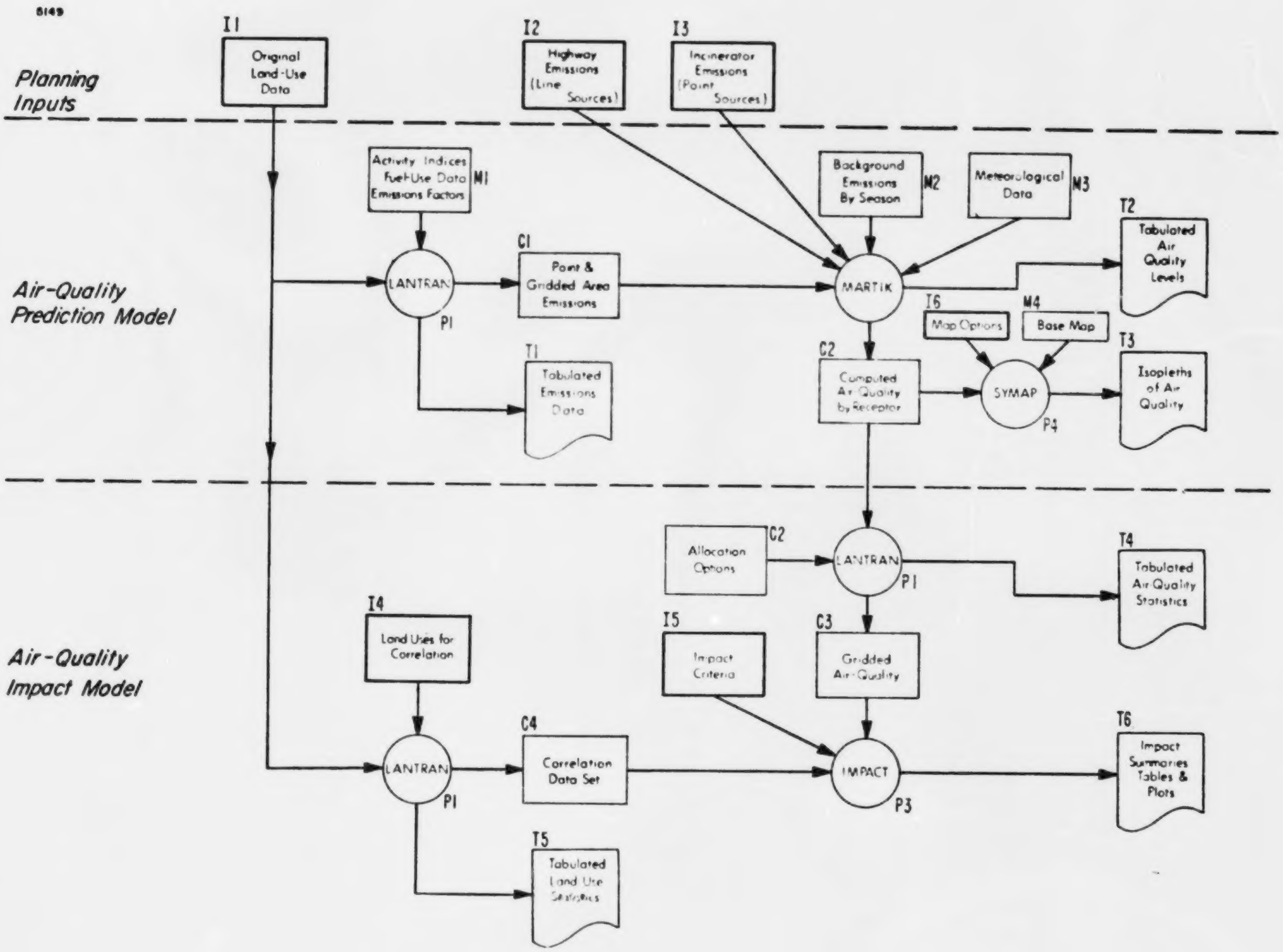
8149
Planning Inputs
Air-Quality Prediction Model
Air-Quality Impact Model
I1
Original Land-Use Data
I2
Highway Emissions (Line Sources)
I3
Incinerator Emissions (Point Sources)
Activity Indices Fuel-Use Data Emissions Factors
M1
Background Emissions By Season
M2
Meteorological Data
M3
LANTRAN
P1
C1
Point & Gridded Area Emissions
MARTIK
T2
Tabulated Air Quality Levels
I6
Map Options
M4
Base Map
T1
Tabulated Emissions Data
C2
Computed Air Quality by Receptor
SYMAP
P4
T3
Isopleths of Air Quality
Allocation Options
C2
LANTRAN
P1
T4
Tabulated Air Quality Statistics
I4
Land Uses for Correlation
I5
Impact Criteria
C3
Gridded Air-Quality
LANTRAN
P1
C4
Correlation Data Set
IMPACT
P3
T6
Impact Summaries Tables & Plots
T5
Tabulated Land Use Statistics

Figure 3 AQUIP Software System

I - Input data set, prepared by the system user.

M - Model parameter data set, established initially for the study conditions, and modified only as necessary for updates to the model.

P - Computation step involving one of the four basic computer programs.

C - Computed data set formed as an output of one computation step and used as an input to another.

T - Tabulated outputs (or line printer graphics) delivered to the system user.

This same basic identification procedure is used consistently in this section as well as in the Task 5 report to enable each element of the AQUIP System to be identified, described and implemented. In the following paragraphs the four principal computer programs, which determine the overall operating modes and capabilities of the AQUIP System, are discussed in terms of their specific functions, information flows, data format requirements and run options. In addition, several of the important points of interaction between the planner and the model are illustrated with some examples of the various uses of the AQUIP programs in the planning process.

2.3.2 Planning Inputs

The objective of the AQUIP System is to test hypothetical configurations of land uses with respect to their impact upon air quality, and to rank them in relation to alternatives. The primary input to the AQUIP System is therefore a numerical description of a land use plan. Thus, the first element of the AQUIP software system involves the preparation of land use data. Ultimately, the necessary form of the numerical description of the plan is an emissions inventory for input to the ERT/MARTIK diffusion modeling program. Although the data could be prepared in this form to begin with, it is more practical (particularly in view of the complex nature of the emissions projection process) to prepare the inputs in a form as close as possible to the actual planning variables.associated with the plan.

For this reason, original land use data are prepared by the user, working directly from a map of the study region. Land use activities are defined, classified, and indicated as point, line, or area "figures" on the map. Area zones are represented as polygons (i.e., bounded by straight-line segments), and highways are represented as connected straight-line segments. Other activities which ultimately can be represented as point emission sources (e.g., power plants) are also indicated.

Each activity region or figure is assigned a set of activity codes and values which define the procedures used to compute its emissions. For example, a residential region could be represented as a polygon figure and assigned a "residential classification code" together with values which determine how it is to be treated in computing emissions. Geographical data for each figure are prepared by coding the coordinates of the vertices of its boundaries. These data are then incorporated into the "original land use data"(I-1), together with the codes and values. The result is a data set describing a land use alternative in terms of planning variables to which the emissions-projection methodologies (described in the Task 1 study report and embodied in the LANTRAN computer program) can be applied. The activity codes used consist of a letter followed by two digits. For example, the letter R was used for residential with the first digit relating to the appropriate land use plan and the second to the density of the particular residential zone. Other types of land use were treated in similar manner. For maufacturing however, the letter S followed by the appropriate 2-digit SIC code was used.

Highways and some types of point source activities (such as power plants and incinerators) are treated separately. In the case of the highway data, the geographical coordinates of the end-points of the various links are coded, together with emissions derived by application of emissions factors to traffic volume projections. These data become the "highway emissions" data set (I-2), used as a direct input to the ERT/MARTIK diffusion modeling program.

Similarly, the geographical coordinates which locate power plants, incinerators, or other point-sources are coded together with direct emission rates and stack parameters determined separately for each source. These data become the "point-source" data set (I-3), used as a direct input to the diffusion model.

2.3.3 Air Quality Prediction Model

Having prepared data sets representing the original land use data as described above, the computation of emissions from the coded area zone activity data is performed by the LANTRAN program. The computation involves the allocation of data defined on the set of figures to a grid-cell system in order to represent the large number of small discrete sources as area sources. Since the diffusion model requires rectangular area sources, LANTRAN transforms figure-based data to grid-based data. In principle, it is emissions defined on the figures which are allocated by LANTRAN; in fact, the program performs one additional step: land use data are first converted to emissions data which are then allocated to the grid system. Some of the emissions data are, however, represented in the output as points, rather than as gridded area sources because: (1) certain activities generate point source emissions (such as schools or hospitals within residential areas); and (2) individual discrete sources with emissions greater than some threshold must be considered separately. The result of this computation step is the "point and gridded area source" data set (C-1) in the form of card decks (corresponding to each averaging period) for use as a direct input to the diffusion model. LANTRAN also produces tabulated output describing the emissions characteristics of the input data, and graphical displays of emission rates by pollutant as allocated to the chosen grid system. An example of such a display is given in Figure 4.

The next step involves the use of the ERT/MARTIK air quality prediction model. This model performs the essential transition from the emissions generated by a particular land use plan to the air quality concentrations associated with the plan. The emissions inventory data sets, (I-2), (I-3) and C-1) as described above, are input to the MARTIK program, along with the model data sets which define the sites (receptors) at which concentrations are to be computed, the meteorological parameters, and the emissions assigned to the "background" region (i.e., the region outside the plan boundaries). The result of this step is a set of computed concentrations for each pollutant, at each of the desired receptor sites. The MARTIK calculations define the "computed air quality" for each appropriate seasonal or annual time-averaging period. The results are printed as a tabulated output (T-2) and are passed to additional AQUIP operations as the data set (C-2). An example of the tabulated output from MARTIK is shown in Figure 5.

The final step involved in the AQUIP air quality prediction model is the plotting of computed air pollution concentrations using the SYMAP program. The result of a SYMAP plotting run is a graphical display (T-3) of the study area, with printer-generated shading proportional to the computed concentration at each point. An example of this contour map is shown in Figure 6. The data used as input to the program is the set of receptor "values" computed by MARTIK and output as the data set (C-2). Data prepared by the system user which consists of options which select the pollutant to be displayed, and control the appearance of the output map.

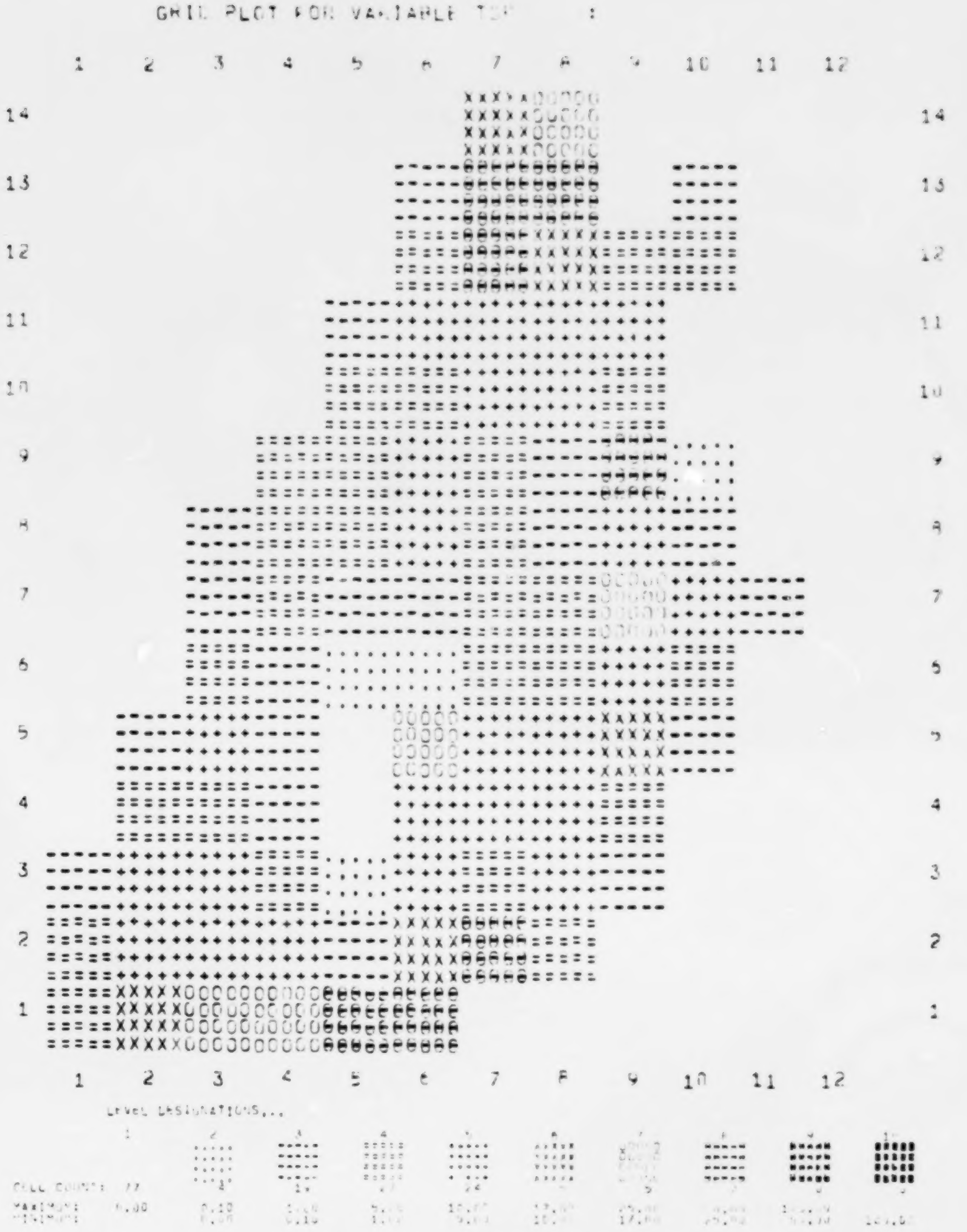
GRID PLOT FOR VARIABLE TSP :
1
2
3
4
5
6
7
8
9
10
11
12
14
13
12
11
10
9
8
7
6
5
4
3
2
1
LEVEL DESIGNATIONS...
CELL COUNT:
MAXIMUM:
MINIMUM:
0.00
0.10
0.00

Figure 4 Graphical Display Showing Emission Rates as Allocated to the Chosen Grid System

```
                 ARITHMETIC MEAN POLLUTANT CONCENTRATIONS

                 COORDINATE SCALE UNIT (METERS)=  1000.000

*************************************************************************************************************
| RECEPTOR | X-COORD  | Y-COORD  |  HEIGHT  | TSP      | SOX      | CO       | HC       | NOX      |
|  NUMBER  | SCALE U  | SCALE U  |  METERS  | UG/M**3  |   PPM    |    PPM   | UG/M**3  | UG/M**3  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|    1     |   579.0  |  4524.0  |    0.0   |  1.6273  |  0.0009  |  0.0181  |  3.8731  |  1.6770  |
|    2     |   578.0  |  4523.0  |    0.0   |  1.5552  |  0.0009  |  0.0160  |  3.4775  |  1.0923  |
|    3     |   579.0  |  4523.0  |    0.0   |  2.2602  |  0.0018  |  0.0360  |  7.2917  |  1.5175  |
|    4     |   580.0  |  4523.0  |    0.0   |  2.4817  |  0.0017  |  0.0330  |  6.7997  |  1.5536  |
|    5     |   578.0  |  4522.0  |    0.0   |  2.0584  |  0.0012  |  0.0218  |  4.7036  |  1.4347  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|    6     |   579.0  |  4522.0  |    0.0   |  2.7549  |  0.0021  |  0.0406  |  8.2080  |  1.8975  |
|    7     |   580.0  |  4522.0  |    0.0   |  2.7940  |  0.0014  |  0.0253  |  5.6915  |  1.6724  |
|    8     |   581.0  |  4522.0  |    0.0   |  2.8914  |  0.0008  |  0.0102  |  3.2236  |  1.9220  |
|    9     |   582.0  |  4522.0  |    0.0   |  3.6530  |  0.0008  |  0.0063  |  2.9710  |  2.3623  |
|   10     |   577.0  |  4521.0  |    0.0   |  1.7340  |  0.0005  |  0.0060  |  1.8957  |  1.2272  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|   11     |   578.0  |  4521.0  |    0.0   |  2.5831  |  0.0011  |  0.0174  |  4.2134  |  1.8467  |
|   12     |   579.0  |  4521.0  |    0.0   |  2.2511  |  0.0013  |  0.0214  |  5.0989  |  2.1032  |
|   13     |   580.0  |  4521.0  |    0.0   |  3.2236  |  0.0010  |  0.0133  |  3.9099  |  2.2114  |
|   14     |   581.0  |  4521.0  |    0.0   |  3.7592  |  0.0009  |  0.0072  |  3.1788  |  2.4970  |
|   15     |   582.0  |  4521.0  |    0.0   |  6.6581  |  0.0012  |  0.0652  |  4.3320  |  3.7172  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|   16     |   583.0  |  4521.0  |    0.0   |  7.7605  |  0.0015  |  0.0042  |  4.6677  |  4.7857  |
|   17     |   577.0  |  4520.0  |    0.0   |  2.1361  |  0.0005  |  0.0050  |  1.9393  |  1.5167  |
|   18     |   578.0  |  4520.0  |    0.0   |  7.7200  |  0.0007  |  0.0069  |  2.5813  |  1.9749  |
|   19     |   579.0  |  4520.0  |    0.0   |  3.2234  |  0.0007  |  0.0065  |  2.7747  |  2.2718  |
|   20     |   580.0  |  4520.0  |    0.0   |  3.6197  |  0.0007  |  0.0052  |  2.7622  |  2.5100  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|   21     |   581.0  |  4520.0  |    0.0   |  4.3339  |  0.0009  |  0.0044  |  3.3115  |  2.2205  |
|   22     |   582.0  |  4520.0  |    0.0   |  6.7634  |  0.0013  |  0.0038  |  4.1013  |  4.1590  |
|   23     |   583.0  |  4520.0  |    0.0   | 14.4047  |  0.0030  |  0.0035  |  7.8435  |  9.0561  |
|   24     |   576.0  |  4519.0  |    0.0   |  1.8093  |  0.0004  |  0.0031  |  1.4469  |  1.2779  |
|   25     |   577.0  |  4519.0  |    0.0   |  2.4644  |  0.0005  |  0.0047  |  2.1047  |  1.7138  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|   26     |   578.0  |  4519.0  |    0.0   |  3.0203  |  0.0006  |  0.0036  |  2.5930  |  1.9667  |
|   27     |   579.0  |  4519.0  |    0.0   |  3.3199  |  0.0006  |  0.0036  |  2.3515  |  2.2179  |
|   28     |   580.0  |  4519.0  |    0.0   |  3.9317  |  0.0007  |  0.0032  |  2.6935  |  2.5367  |
|   29     |   581.0  |  4519.0  |    0.0   |  5.8737  |  0.0010  |  0.0032  |  3.5116  |  3.1703  |
|   30     |   582.0  |  4519.0  |    0.0   | 10.1500  |  0.0021  |  0.0030  |  5.7107  |  6.6346  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
|   31     |   583.0  |  4519.0  |    0.0   | 14.4849  |  0.0030  |  0.0027  |  7.8013  |  9.2564  |
|   32     |   576.0  |  4518.0  |    0.0   |  2.0763  |  0.0004  |  0.0030  |  1.5794  |  1.4355  |
|   33     |   577.0  |  4518.0  |    0.0   |  2.7417  |  0.0005  |  0.0044  |  2.2476  |  1.8546  |
|   34     |   578.0  |  4518.0  |    0.0   |  3.1616  |  0.0006  |  0.0041  |  2.4200  |  2.0331  |
|   35     |   579.0  |  4518.0  |    0.0   |  3.3509  |  0.0006  |  0.0027  |  2.2400  |  2.1408  |
*----------*----------*----------*----------*----------*----------*----------*----------*----------*
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Figure 5   Example of the Tabulated Output of the MARTIK Program

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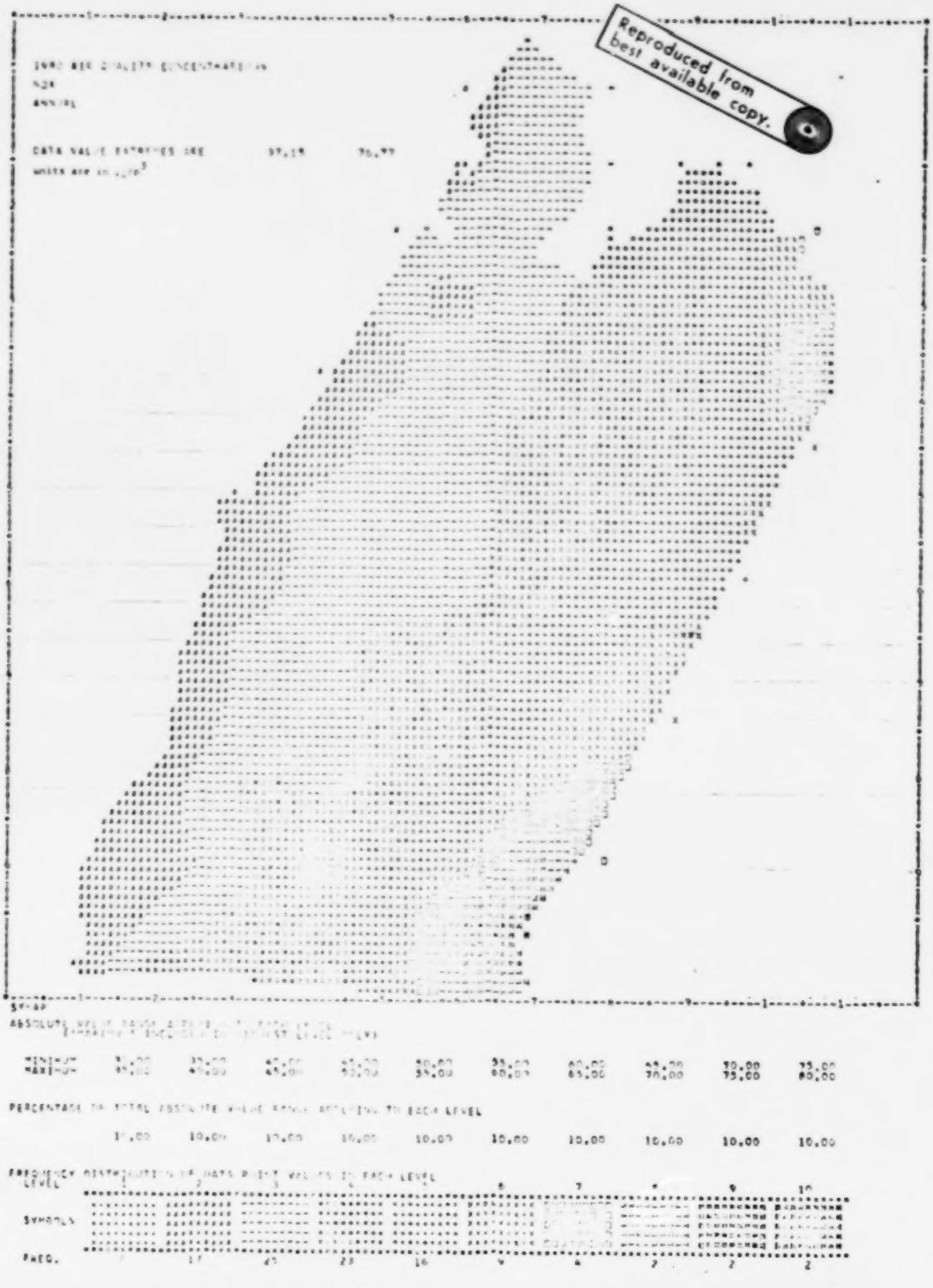
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Figure 6 Example of SYMAP Computer-Generated Air Quality Contour Map

2.3.4 Air Quality Impact Model

The initial step in the use of the air quality impact model is the preparation of land use and other data for correlation with air quality data. In this step, subsets of the original land use data are selected and processed for correlation with the predicted air quality associated with the plan. The computations involved in this process are performed by the LANTRAN program. Operation of the program is similar to its use in the preparation of emissions data, except that, instead of emissions defined on a set of land use figures, the quantities allocated are variables such as population density and acres of industrial land use. The result of this step is a data set, referred to as the "correlation data set" (C-4), which is created in the form of an output card deck for input to the IMPACT program. In addition, grid plots of each selected land use can be generated (see, for example, Figures 33 to 36).

The result of a diffusion analysis with the ERT/MARTIK program is a set of concentrations computed for the given receptor sites. However, in order to perform the impact analysis, these results must be converted to mean air quality defined on the grid system chosen for analysis. This conversion is performed by the LANTRAN program, which constructs a mean surface through the receptor points and then assigns to each cell of the grid system the surface value at the cell center. This step is necessary since there is no direct relationship between the spacing or distribution of receptor points and the grid system used in the impact analysis model. The computation step may be performed routinely, with no interaction from the user (other than to define the grid system). The results of the air quality prediction model calculations are contained in the data set (C-2) produced by the ERT/MARTIK program and used as an input to LANTRAN. The tabulated output from LANTRAN lists the concentrations as allocated to each grid cell, and a corresponding graphical output can be generated if desired (see, for example, Figures 13 to 32). Output from the program is the gidded air quality data set (C-3) and is used as an input to the impact analysis procedures.

The final step in the AQUIP modeling system is the analysis of the air pollution impact of the original land use data. This step brings together the various data sets of the system, such as land use data or concentrations data. for final evaluation and ranking of planning alternatives. The planner interacts directly with the AQUIP model at this point by defining the criteria by which the plan and its alternatives are to be ranked, and by specifying the desired set of operations to manipulate the data sets. The planner codes these analytical procedures into the IMPACT computer program using a simple "hyper-language". Any number of gridded data sets may be brought together, and any number of new data sets can be created. In general, the specified analytical operations produce quantitative information for each cell of the grid system. The results are tabulated and can be presented graphically as grid plots. Examples of the types of analyses which may be performed using the IMPACT Program include the comparison of projected air quality with air quality standards, the correlation of air quality data with land use data, the display of specific land use data (for example, the location of critical receptors), the calculation of impact parameters, and the calculation of plan ranking indices.

2.4 Estimation Procedures for Rapid Plan Evaluation and Ranking

The AQUIP System is a tool for the consideration of air pollution at levels of detail and accuracy essential to providing meaningful inputs to decision-making in the planning process. As indicated in the previous section, the AQUIP System software automates a number of lengthy and complex data processing steps necessary for the analysis of air quality and the evaluation and ranking of comprehensive land use plans, including, for example, the calculation of emissions from land use data, the projection of pollutant concentrations, the calculation of impact parameters, and the tabular and graphic display of results.

It is also recognized, however, that planners need a means for the rapid evaluation of land use patterns at very early stages in the plan design where the level of detail and accuracy is not as important as the need for quick answers. In an effort to respond to this need, we have developed a highly simplified methodology for plan evaluation and ranking based on the estimation of total emissions. The methodology is based on the use of the emission estimation factors listed in Table 4. These factors represent annual emissions per unit area for each land use category (or emissions per unit activity in the case of motor vehicles). Because of their limited accuracy such factors can be used only for gross planning estimates and guidelines. In brief, the procedures include the following steps:

1. For a given plan, classify the land uses and activities according to the categories listed in Table 4, and estimate the number of acres of each land use category (or the number of VMT in the case of highways).
2. Calculate the pollutant emissions for each land use category by applying the annual emission rates listed in Table 4.

TABLE 4

SUMMARY OF ESTIMATED 1990 ANNUAL EMISSION RATES FOR HACKENSACK MEADOWLANDS LAND USE CATEGORIES

Land Use Category	Pollutant Emissions (lb/year/acre)				
	TSP	SO_2	CO	HC	NO_x
Residential					
10 Dwelling units/acre	25	1	35	12	7
20 " " "	180	120	4	54	85
30 " " "	180	120	4	54	85
50 " " "	250	160	5	75	120
80 " " "	200	140	4	63	100
Commercial & Industrial					
Commercial	60	45	1	12	95
Manufacturing					
Light	1100	1100	10	140	850
Heavy	5400	5400	60	900	5400
Research	2	15	1	5	35
Distribution	60	45	1	12	95
Special Use	60	45	1	12	95
Airport(1)	100	1000	3000	350	100
Transport Center	180	130	2	36	300
Cultural Center	45	35	1	9	70
Open Space	0	0	0	0	0
Other(2)	Emission Factors				
Highway (lb/10^6 VMT)	700	400	11000	1000	1500
Parking Lots (lb/10^3 hrs idling)	4	4	12	3	1

(1) Assumes 400,000 flights/year from Teterboro Airport, and 700 acre area.

(2) Activities are not specified on basis of emissions/unit area.

3. Calculate the total annual plan emissions for each pollutant by summing the emissions resulting from each land use category.
4. Rank alternative land use plans on basis of resultant total pollutant emissions.

The application and interpretation of these procedures are subject to many conditions which limit their accuracy and general applicability. A primary limitation is due to the fact that the emissions estimation factors listed in Table 4 are derived from the results of the Hackensack Meadowlands planning data and assumptions, specifically for the 1990 time period, and thus cannot reasonably be expected to coincide with assumptions involved in other regional planning situations. A second basic limitation is that these procedures give no indication of the resultant pollutant concentration levels or spatial patterns. A third limitation is that these procedures do not take into account the influence of background emissions (i.e., the influence of sources of pollution outside the planning region on air quality within the planning region). A final major limitation is the accuracy of the emission estimation factors themselves. The emission rates listed in Table 4 represent averages over very broadly defined land use categories; a detailed examination would indicate that specific emission rates for different types of industrial developments (or even residential developments) may vary by factors ranging from 10 to 1000. Thus the listed emission rates for each land use category can only be regarded as gross estimation factors.

Despite such limiting factors, these simplified procedures can be useful to the planner since: (1) they provide a means for rapid estimation of the air pollution potential of land use plans; (2) they are simple, easy to apply, and do not require a computer; and (3) they permit the planner to examine the sensitivity of changes within a given plan and to rank alternative plans. Results of the application of these procedures to the Meadowlands plans are illustrated in Section 3.3.

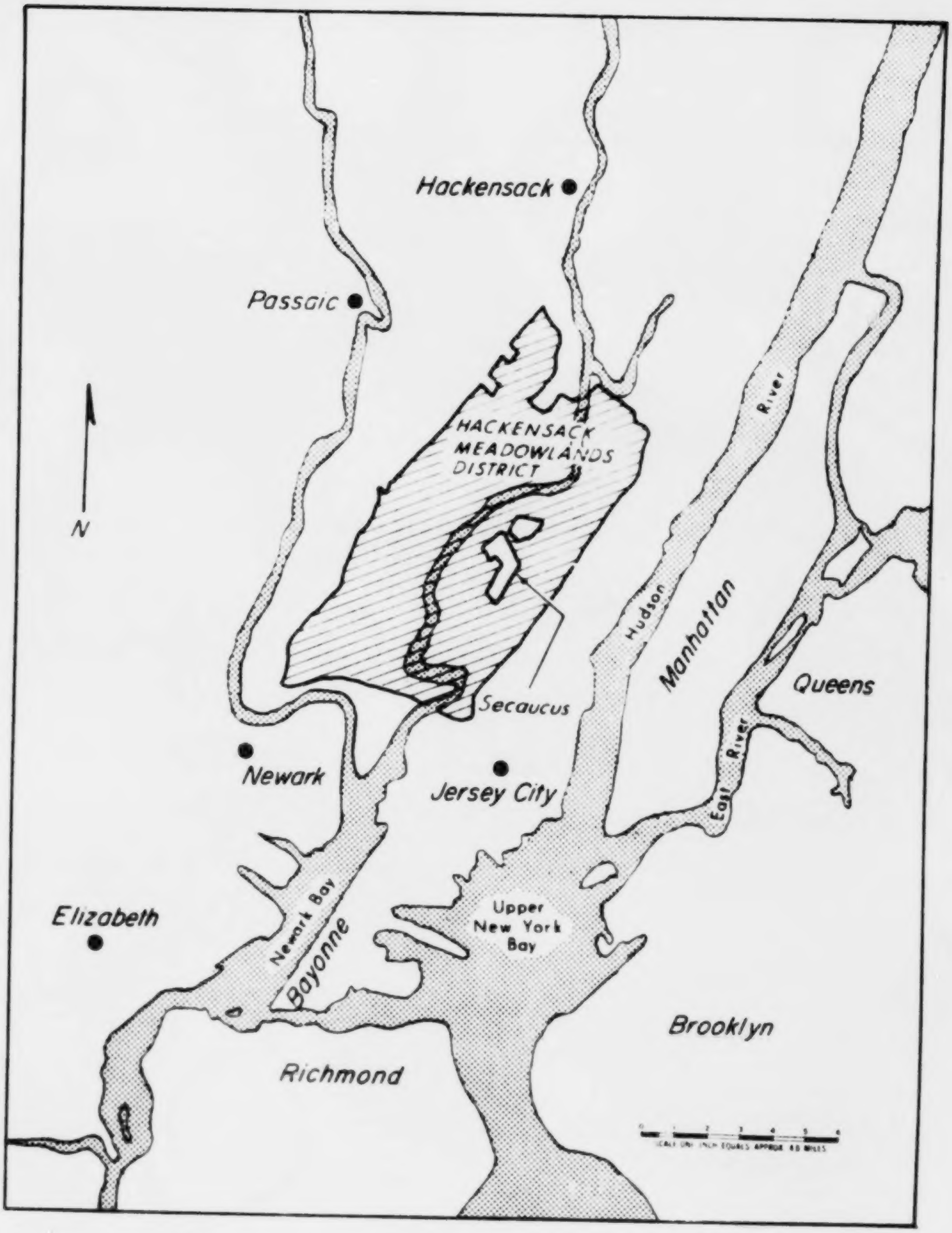
3. ILLUSTRATION OF PROCEDURES FOR AIR QUALITY ASSESSMENT OF LAND USE PLANS

The objective of the material presented in this section is to illustrate the use of the AQUIP System in the planning process by describing the results of the application of these analytical methodologies to the assessment of the air pollution impact of the four alternative land use plans developed by the Hackensack Meadowlands Development Commission (HMDC). (A complete discussion of the procedures and the resultant evaluation and ranking of plans is contained in the Task 3 Report.)

3.1 Characteristics of the Hackensack Meadowlands Land Use Plans

The New Jersey Hackensack Meadowlands District is a tract of land measuring approximately four miles by eight miles (or roughly 6.5 km by 13 km) extending in a north-south direction along the Hackensack River. As shown in Figure 7, the Meadowlands is located at the hub of the New York - New Jersey metropolitan area. Within a five-mile (roughly 8 km) wide zone around the Meadowlands is Manhattan immediately across the Hudson River to the east, Jersey City and Newark to the south, Paterson and Pasaic to the northwest, and Hackensack to the North.

Today, the Hackensack Meadowlands consists largely of meadows, marshes, and salt-water swamps. Of its nearly 20,000 acres (approximately 100 km^2) only 7,000 are committed to permanent uses. These consist largely of transportation networks (highways, railroads, and an airport), distribution centers (freight terminals, warehouses, storage tanks, and utility transmission lines), and solid waste disposal (over 30,000 tons per week from more than 100 municipalities.)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HACKENSACK MEADOWLANDS DISTRICT
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Hudson
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Manhattan
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Newark
Jersey City
Elizabeth
Newark Bay
Bayonne
Upper New York Bay
Brooklyn
Richmond
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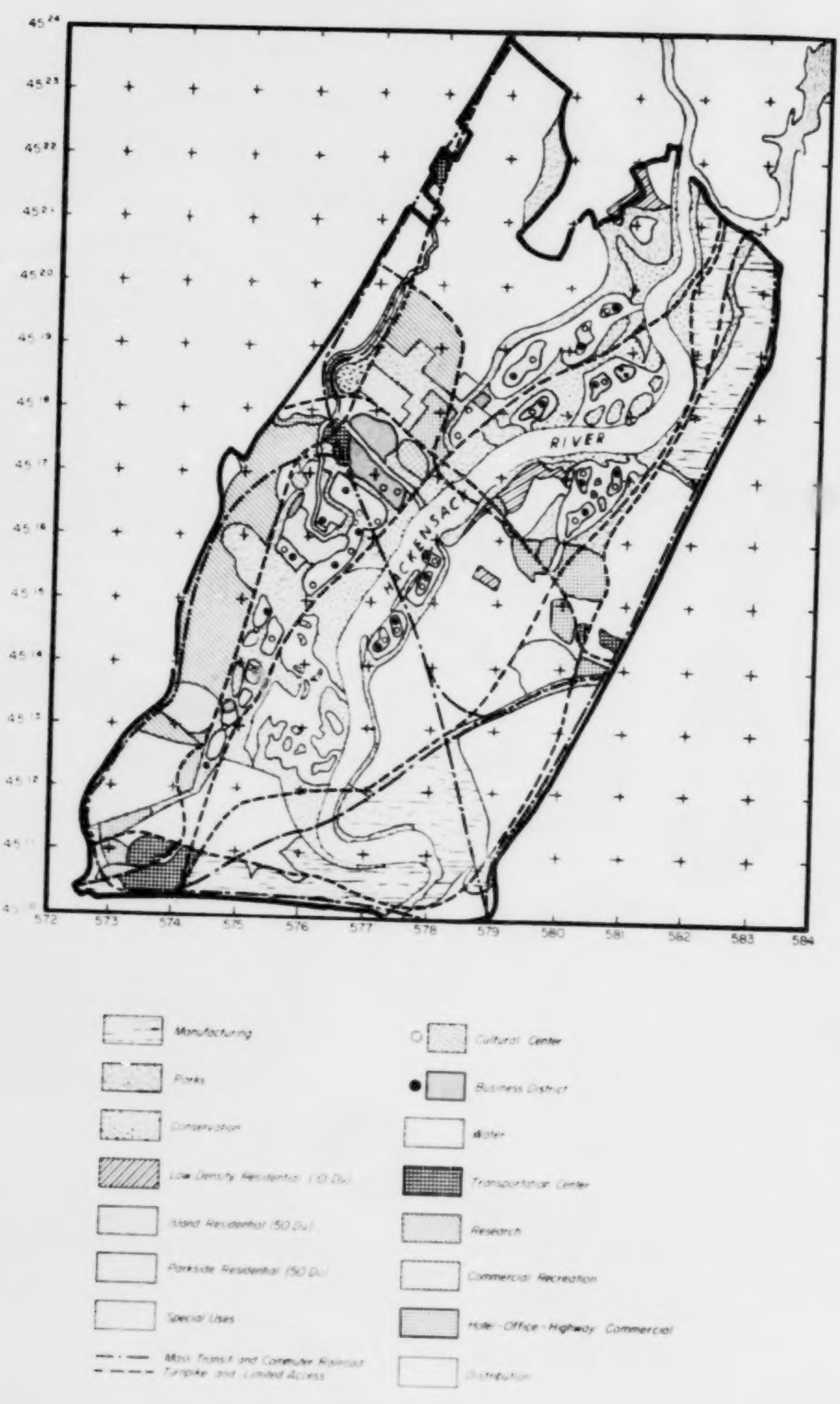
Figure 7 Location of the Hackensack Meadowlands District

In 1968 the New Jersey legislature passed the "Hackensack Meadowlands Reclamation and Development Act"[27] creating a commission having the authority to prepare, adopt, and implement a master plan for the orderly development of the district. As a consequence, a number of alternative comprehensive land use plans have been prepared to complement previous development in the district and to correct existing imbalances in regional land uses. The four specific plans analyzed in this study are designated as:

Plan 1 - The Master Plan[28]
Plan 1A - Self-Supporting New Town
Plan 1B - Expansion of New York City Urban Core
Plan 1C - Trend Development Based on Current Zoning

These plans are shown in Figures 8 through 11. The basic data and assumptions concerning the land uses for each of the plans were supplied by the HMDC and were processed and coded for input to the AQUIP System. The resultant percent mix of land use categories, together with population and traffic projections for the different plans are summarized in Table 5.

The four plans show significant differences both in the relative location of land uses and in the percent mix of land use categories. Plan 1, the Master Plan, is characterized by a large amount of open space (31% including open water), a relatively low population (148,000), and a broad mix of industrial and commercial activities. The dominant feature of the plan is the expansive area along the Hackensack River devoted to parks and conservation land. Only 6% of the total area is allocated to residential area, which consists mostly of high density island high-rise apartments and parkside residential areas located at points within this open space region. The business and commercial activities are located primarily in the central region of the Meadowlands west of the Hackensack River. Industrial activi-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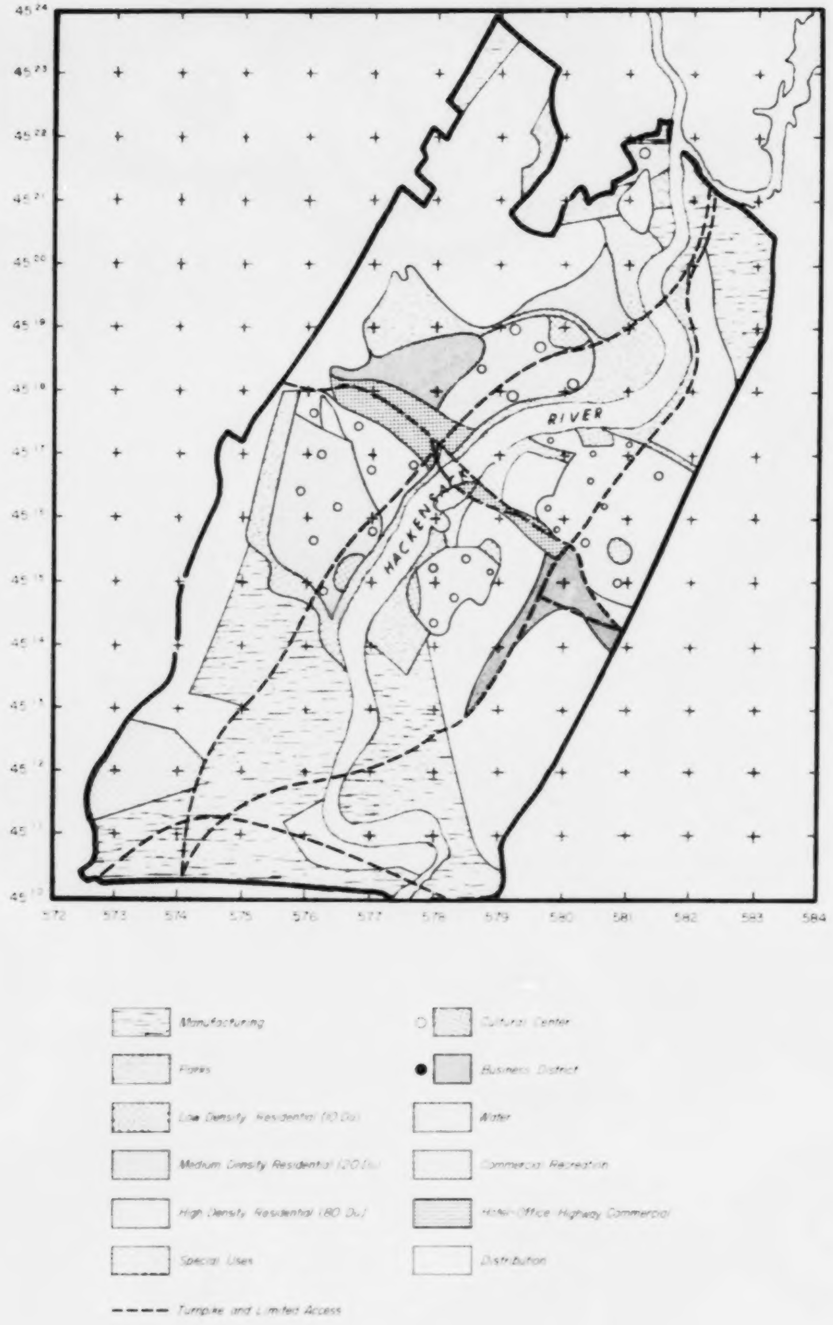
HACKENSACK
RIVER
Manufacturing
Parks
Conservation
Low Density Residential (10 DU)
Island Residential (50 DU)
Parkside Residential (50 DU)
Special Uses
Mass Transit and Commuter Railroad
Turnpike and Limited Access
Cultural Center
Business District
Water
Transportation Center
Research
Commercial Recreation
Hotel-Office-Highway Commercial
Distribution

Figure 8 Alternative Meadowlands Land Use Plan No. 1--The Master Plan



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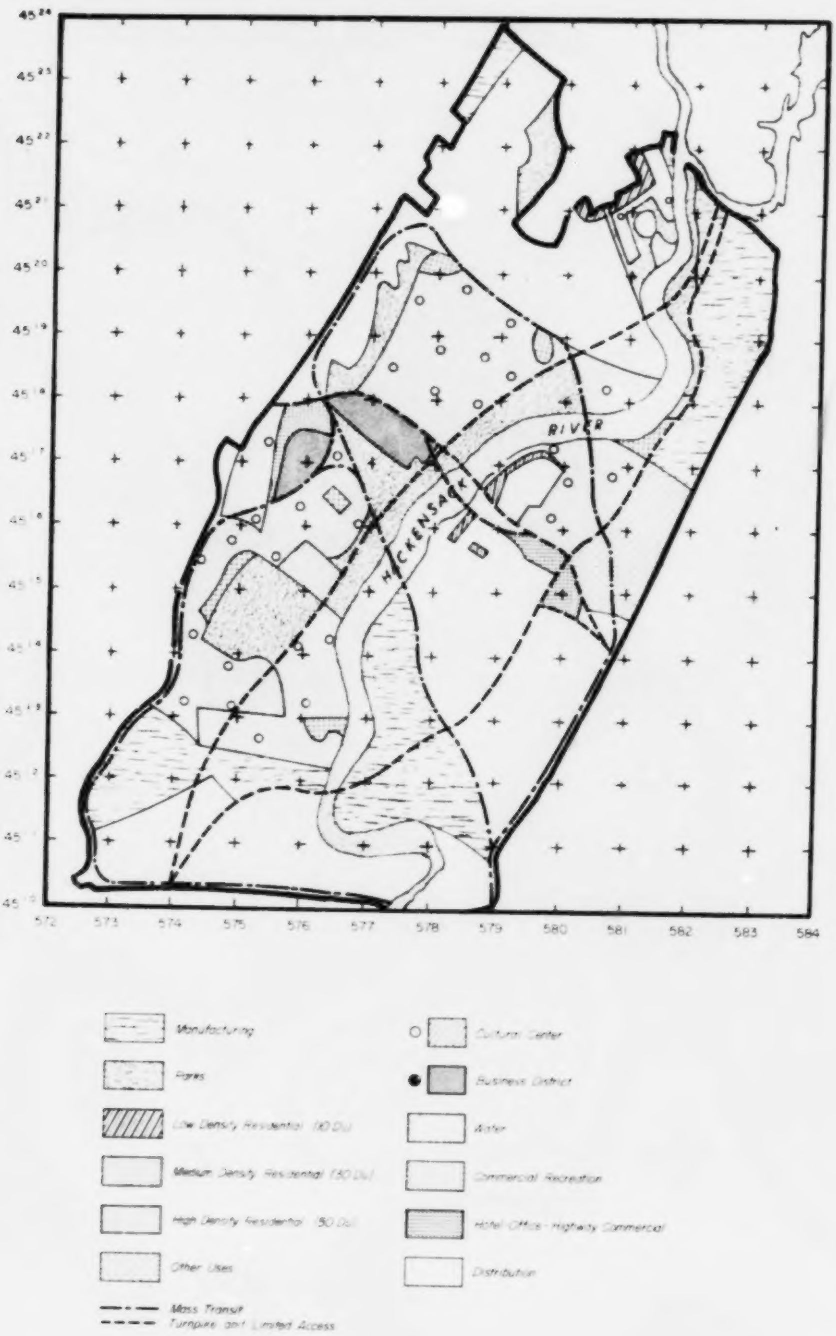
Special Uses
Turnpike and Limited Access
Cultural Center
Business District
Water
Commercial Recreation
Hotel-Office Highway Commercial
Distribution

Figure 9 Alternative Meadowlands Land Use Plan No. 1A--Self-Supporting New Town



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HACKENSACK
RIVER
Manufacturing
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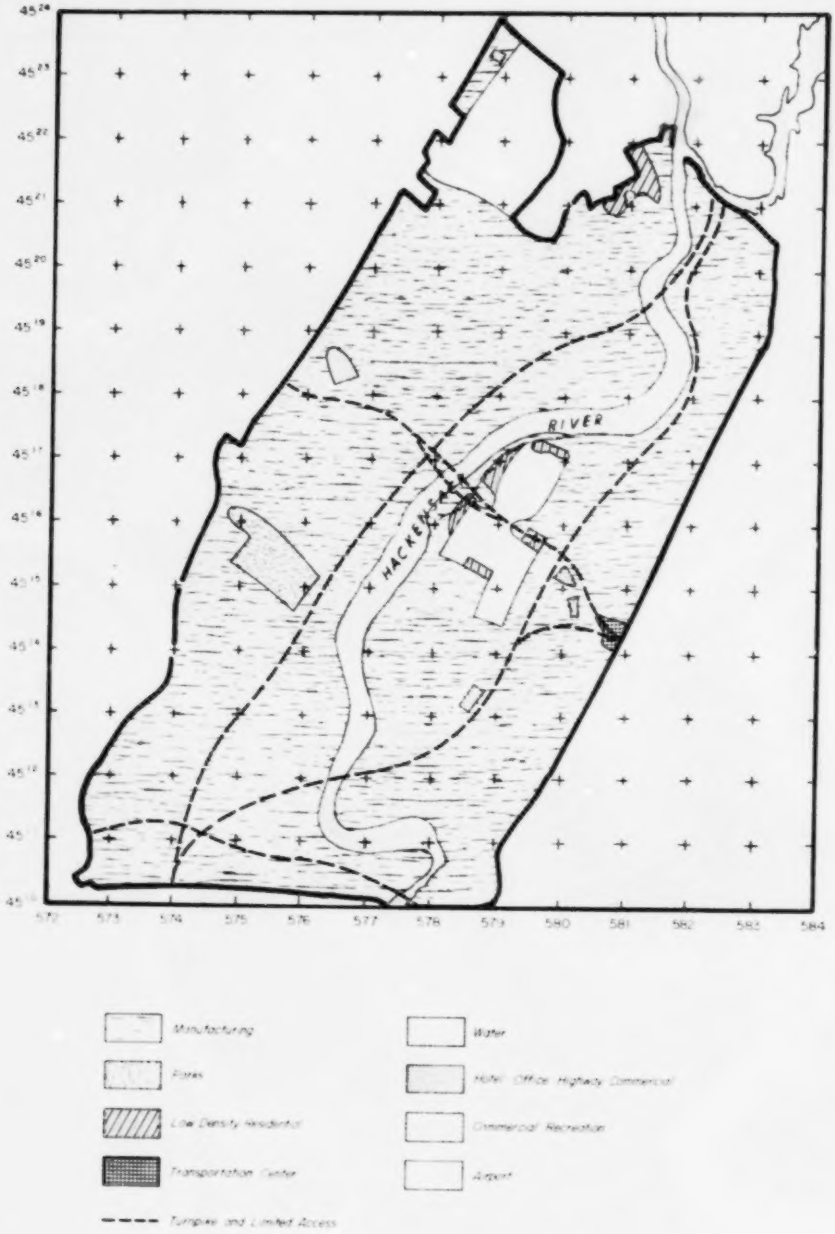
Low Density Residential (10 D.U.)
Medium Density Residential (30 D.U.)
High Density Residential (50 D.U.)
Other Uses
Cultural Center
Business District
Water
Commercial Recreation
Hotel-Office-Highway Commercial
Distribution
Mass Transit
Turnpike and Limited Access

Figure 10 Alternative Meadowlands Land Use Plan No. 1B--
Expansion of New York City Urban Core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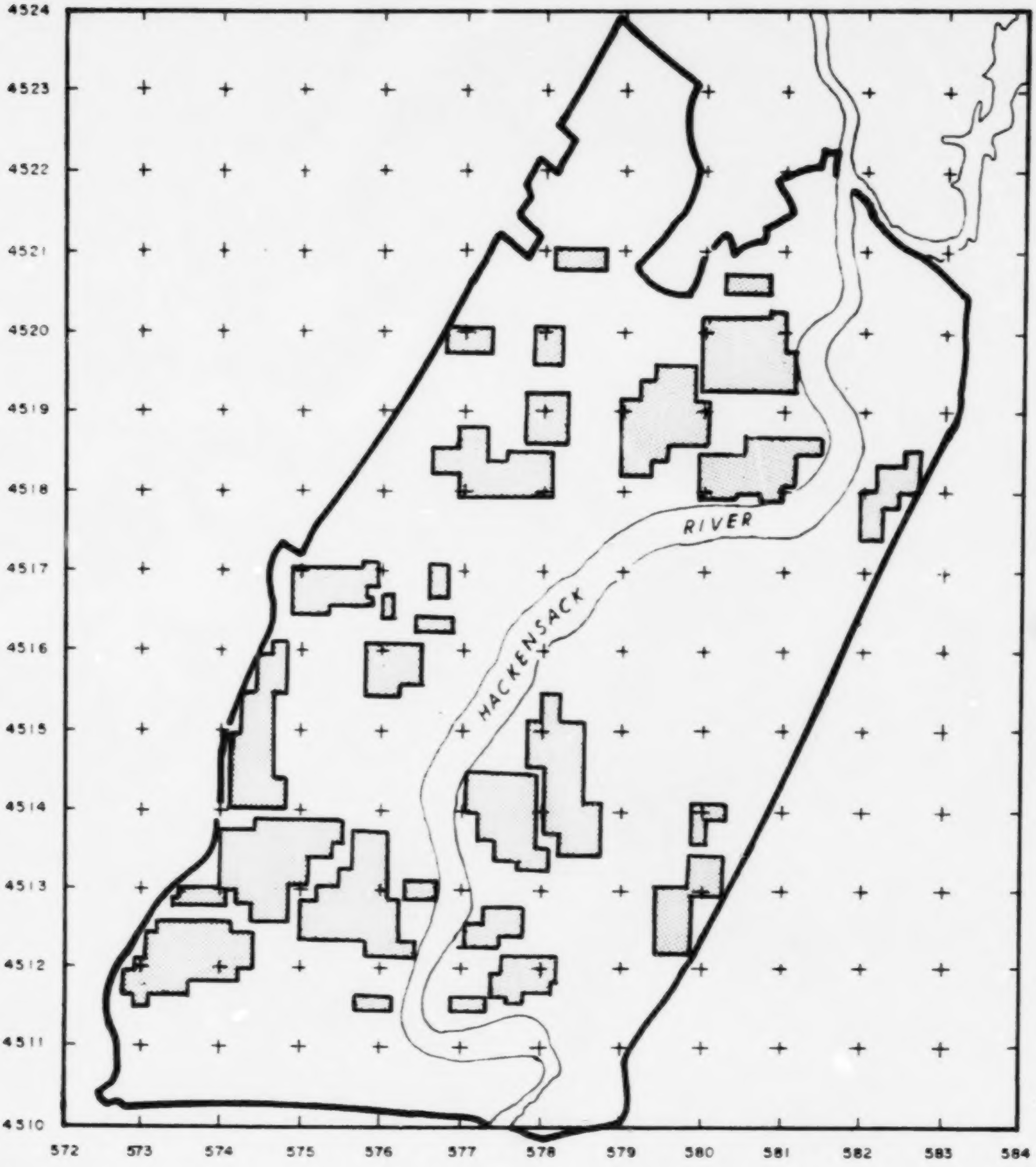
Commercial Recreation
Airport

Figure 11 Alternative Meadowlands Land Use Plan No. 1C--Trend Development Based on Current Zoning



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HACKENSACK
RIVER

Figure 12 Location of Manufacturing and Industrial Land Use Categories for Plan 1C

TABLE 5

SUMMARY OF LAND USE INFORMATION FOR HACKENSACK MEADOWLANDS PLANS

Land Use Categories	Percent of Total Plan Area			
	Plan: 1	1A	1B	1C
Residential(1)				
10 DU/AC (dwelling units/acre)	1	2	1	1
20 DU/AC		7		
30 DU/AC			5	
50 DU/AC	5		15	
80 DU/AC		8		
TOTAL	6	17	21	1
Commercial & Industrial(1)				
Commercial	4	4	3	1
Manufacturing (light & heavy)	8	14	15	18
Research	8	0	0	0
Distribution	22	19	22	50
Special Use	1	0	0	0
Airport & Transportation Center	5	4	4	4
TOTAL	48	41	44	73
Open Space(1)				
Water	11	7	7	7
Parks & Conservation	20	11	11	2
TOTAL	31	18	18	9
Other(1)				
Highway & Railroad	12	21	15	14
Special	3	3	2	3
TOTAL	15	24	17	17
TOTAL LAND AREA (19,600 acres)	100%	100%	100%	100%
Total Population(2)	147,604	408,080	469,788	8,161
Total Students(2)	25,758	59,689	114,647	0
Total VMT/Year ($x10^6$)(3)	1,040	1,405	1,515	970

(1) As coded from land use maps -- figures used may not correspond exactly with original estimates given by the HMDC.

(2) As computed from land use data.

(3) Totals include the regional network traffic of $930x10^6$ VMT: in addition, $4x10^6$ hrs. idling/yr. are assumed for parking lots for all plans.

ties (i.e., manufacturing, 8%, and distribution, 22%) are largely located in the eastern half of the region, although a sizable area (8%) devoted to research industry is located along the western border of the district. Plan 1 also includes various modes of public transportation, including novel means of waterborne transit, as well as new roadways. Arterials servicing the high density residential areas are located to minimize local surface street traffic.

In contrast, Plan 1A, the Self-Contained New Town, is characterized by a higher population (408,000), greater residential area (17%), and less open space (18%). The open space areas are predominantly located on the fringes of residential areas, acting as buffers to surrounding industrial areas. The primary commercial and industrial land use activities are devoted to manufacturing (14%) and distribution (19%). A significant feature of this plan is that essentially all of the population is located within the central portion of the planning region, spread from west to east, with low density areas in the west and extremely high density areas in the east. Furthermore, nearly all manufacturing activity is located in the southern portion of the planning region, while distribution activities are located in both the eastern portion of the region and in the vicinity of Teterboro airport. Characteristically, major access roadways are on the fringe of the residential areas to reduce surface street traffic. Since it is assumed that employment will be served mostly by local population, and that most of the journey to work trips will be served by the local roadway system, a significantly high percentage of land use is devoted to highways (21%). Moreover, no rapid transit is indicated in the plan. Consequently, the total miles of vehicular traffic projected for this plan (1.4 billion VMT/year) reflects both the higher population and the increased levels of local traffic.

Plan 1B, the New York City Urban Core Expansion, is nearly identical to Plan 1A in percent mix of land use categories but has a significantly different location of these land use activities within the planning region. The primary difference is that nearly all residential area (21%) is located in the western part of the district; and while Plan 1A has areas of low and extremely high density dwelling units, Plan 1B has mostly intermediate density areas. The eastern portion of the Meadowlands is predominantly devoted to commercial and industrial land use activities. Manufacturing (15%) is widely dispersed, being located mostly in the southern and northeastern portions of the district. Distribution (22%) is similarly dispersed widely throughout the region. Again, as in Plan 1A, open space is used as a buffer between residential and industrial areas, and to expand the open space along the river. Plan 1B has the largest projected population (nearly 470,000) and the largest projected amount of traffic (over 1.5 billion VMT/year) of the four plans. Because of its planned close relationship to the New York City urban core, this plan also contains a substantial amount of rapid transit and commuter railroads in addition to new arterials to serve the residential areas.

Plan 1C, the Trending of Current Zoning, is significantly different from the other three plans in the percent mix of land uses. It contains less than 1% residential area (to serve a projected population of approximately 8,000), while having little open space (9%) except for that associated with open water. Most of the region is devoted to commercial and industrial activities (73%), primarily distribution (50%). Industrial areas (18%) were allocated by the HMDC to 10-acre plots as shown in Figure 12. Furthermore, because of the low population, this plan also has the lowest projected traffic (0.97 billion VMT/year), reflecting primarily the regional network traffic.

3.2 Summary of Plan Evaluation and Ranking

3.2.1 General Objectives and Criteria for the Air Quality Analysis

The basic objective of this analysis was to demonstrate the procedures and methodologies developed for considering air pollution in the planning process through the direct application of such methodologies to the planning alternatives developed for the Meadowlands. Regional air pollutant concentrations for total suspended particulates (TSP), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_X) were analyzed in terms of annual averages and summer and winter seasonal averages. The analysis also included the influence of sources outside the Hackensack Meadowlands (i.e., background sources) on air quality within the planning region.

The evaluation of the four alternative Hackensack Meadowlands 1990 Comprehensive Land Use Plans was based primarily on the considerations of:

1. Compliance with ambient air quality standards.
2. The influence of background concentrations on total air quality within each plan.
3. Average regional air pollutant concentration levels.
4. The percent variation in total air quality among the plans on a pollutant by pollutant basis.
5. Average exposures of critical receptors and land use categories to pollutant concentrations.

In order to assess compliance with standards, the calculated annual average pollutant concentrations must be compared to corresponding annual average standards. As shown in Table 6 standards based on annual average concentrations do not exist for all pollutants, and such direct comparisons cannot be made. As a result, equivalent values of ambient air quality standards for annual time-averaging periods were derived where both possible and meaningful. The resultant standards (or their extrapolated equivalents) as used in this analysis are summarized in Table 7, along with an indication of the method of derivation. As noted in Table 7, the standards used for comparison are the Federal secondary and New Jersey ambient air quality standards.

A qualitative evaluation of plans was carried out by means of a visual examination of air quality contours and the subjective correlation of such contours with the land use categories of each plan. A quantitative analysis and evaluation of plans was carried out by the calculation of quantitative measures of impact. This quantitative evaluation was based primarily on "averaged" impacts (such as average regional concentration levels or average levels of exposure to specific receptors) rather than "integrated" impacts (which are proportional to both average concentration levels and the total number of receptors affected).

In addition to these criteria, the evaluation of the plans was subject to other constraints and general considerations. In particular the analysis was oriented toward regional effects based on the calculation of mean annual pollutant concentration levels. The analysis considered the effects on regional air quality and on critical receptors resulting primarily from differences among the four plans in: (1) the percent mix of land use categories; (2) the relative locations of land uses; and (3) the relative intensity of land use activities. The relationships between pollutant concentrations and impacts such as health effects and socio-economic consequences were not considered. Moreover, the analysis did not consider localized or

TABLE 6

Federal Ambient Air Quality Standards Adopted by Environmental Protection Agency April 30, 1971; New Jersey Ambient Air Quality Standards for Sulfur Dioxide and Particulates

μg/m^3 (ppm)[5]

Pollutant	1-hr max conc.[1]	3-hr max conc.[1] 6 am - 9 am	3-hr max conc.[1]	8-hr max conc.[1]	24-hr max conc[1]	Annual Average
Sulphur Oxides as SO_2						
Primary Federal Std.					365 (0.14)	80 (0.03)[2]
Secondary Federal Std.			1300 (0.5)[9]		260 (0.1)	60 (0.02)[2]
N.J. Std., (Chapt.13)	668 (0.25)[6]				267 (0.10)[6]	53 (0.02)[2]
" "	534 (0.20)[7]				214 (0.08)[8]	45 (0.017)[3]
Particulates						
Primary Federal Std.					260	75[3]
Secondary Federal Std.					150	60[3]
N.J.Std.,(Chapt.13)					195[6]	65[3]
Carbon Monoxide						
Primary & Secondary Fed.Std.	40,000 (35)			10,000 (9)		
Hydrocarbons as CH_4						
Primary & Secondary Fed.Std.		160 (0.24)[4]				
Photochemical Oxidants as O_3						
Primary & Secondary Fed.Std.	160 (0.08)					
Nitrogen Dioxide as NO_2						
Primary & Secondary Fed.Std.						100 (0.05)[2]

[1] Maximum Values in Federal Standards are not to be exceeded more than once per year.
[2] Arithmetic mean
[3] Geometric mean
[4] Nonmethane hydrocarbons, expressed as methane (CH_4), for the 3-hr period 6 am - 9 am.
[5] Conversions from micrograms per cubic meter to parts per million are made at one atmosphere pressure and 25° C for Federal standards - 20° C C for New Jersey standards.
[6] Arithmetic average concentration not to be exceeded and to be attained no more than once in twelve consecutive months.
[7] Arithmetic average concentration to be attained or exceeded no more than nine times in twelve consecutive months.
[8] Arithmetic average concentration to be attained or exceeded no more than four times in twelve consecutive months.
[9] Any maximum three hour concentration not to be exceeded more than once per year.

Source: Environmental News Press Release, Friday, April 30, 1971; National Primary and Secondary Ambient Air Quality Standards New Jersey Air Pollution Control Code, Chapter 13, Air Quality Standards

TABLE 1

EQUIVALENT ANNUAL AVERAGE AIR QUALITY STANDARDS

Pollutant	Standard(1)		Derivation
	($\mu g/m^3$)	(ppm)	
TSP	70.1	--(3)	From N.J. (geometric mean) annual standard(2)
SO_2	53.0	0.02	N. J. annual standard
CO	1425.0	1.25	Extrapolation from Federal 8-hour standard using statistics from N.J. measurements data (2)
HC	160.0	0.24(3)	Federal (secondary) 3-hour standard(4)
NO_X	100.0	0.05(3)	Federal (secondary) annual standard

(1) Annual arithmetic mean, never to be exceeded

(2) Extrapolations based on use of Larsen Model. (Larsen, R.I. : "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards", Office of Air Programs Publication. No. AP-89, EPA, Office of Air Programs, Research Triangle Park, N.C., 1971.)

(3) Conversion to ppm not strictly possible without specifying composition of pollutant: HC is based on CH_4; NO_x is based on NO_2.

(4) Extrapolation of 3-hour (6 to 9 AM) standard to an annual standard not considered valid.

microscale impacts. Finally, the analysis did not consider the interrelationship between air pollution effects and other environmental concerns such as water quality or solid waste disposal.

3.2.2 Results of Plan Evaluations

It was found that all four land use plans behaved similarly relative to compliance with ambient air quality standards. As indicated in Table 8, three of the pollutants, SO_2, CO, and NO_X, were found to comply with standards in all plans. Two of the pollutants, TSP and HC, were found to exceed ambient air quality standards in all four plans.

Visual examination of the air quality contours illustrated in Figures 13 to 32 for mean annual concentrations, showed relatively small but distinctly observable variations among the plans for each given pollutant, with the exception of HC. As shown in Table 8 it was found that background concentration levels represent 65% to 99% of total air quality within the region (depending on the specific plan and pollutant) and thus represent the most significant influence on concentration levels and spatial patterns for each of the plans and each of the pollutants.

It was concluded that particulates represent a critical air pollution problem in all plans since projected background concentrations as well as projected total concentrations exceed standards in the 1990 time period. On the other hand, SO_2 is not considered to be a critical problem in terms of regional air quality since predicted concentration levels are well within the limits of the ambient air quality standard. Furthermore, the observed variation in impacts on average regional air quality among Plans 1, 1A, and 1B is less than 6% (as indicated by the average total area exposure impact parameter in Table 9) while the impact of Plan 1C on regional air quality

TABLE 8

SUMMARY OF PROJECTED 1990 AIR QUALITY DATA FOR THE MEADOWLANDS

Pollutant	Plan	Ratio of Total AQ to Annual AQ Standard		Background AQ as % of Total AQ	
		Minimum	Maximum	Minimum	Maximum
TSP	1	1.51	2.46	95	97
	1A	1.55	2.44	86	92
	1B	1.53	2.56	95	99
	1C	1.62	2.52	77	89
SO_2	1	0.34	0.55	85	95
	1A	0.37	0.58	75	88
	1B	0.35	0.56	78	88
	1C	0.40	0.61	64	96
CO	1	0.54	0.67	95	99
	1A	0.56	0.69	90	94
	1B	0.56	0.91	87	95
	1C	0.54	0.66	95	99
HC	1	8.65	12.3		99
	1A	8.69	12.3		99
	1B	8.78	12.3		99
	1C	8.73	12.3		99
NO_X	1	0.42	0.64	94	98
	1A	0.43	0.64	86	98
	1B	0.42	0.64	90	98
	1C	0.44	0.65	78	90

is 15% greater than for Plan 1. This indicates that Plans 1, 1A, and 1B are highly preferable to Plan 1C in terms of average SO_2 air quality.

Air pollutant concentrations for CO are not considered to be a critical problem on the regional scale for Plans 1, 1A, and 1C, since concentrations are well within the ambient air quality standards. In Plan 1B, however, air quality reaches approximately 90% of the standard and thus becomes an issue of critical concern, especially since under such circumstances localized concentrations resulting from short period peak traffic conditions have a high probability of exceeding standards.

Air quality for HC is a critical consideration in all plans because of the large factor by which standards are exceeded. Just how critical it is, however, depends strongly on the goals and judgment of the planner, especially since the primary concern for HC is with effects on plant life and the formation of photochemical oxidants rather than with direct health effects. Furthermore, since background levels represent on the order of 99% of total air quality in all plans, it is clear that land use planning for the Hackensack Meadowlands alone is an ineffective approach to abating HC air quality problems. However, by appropriately locating critical receptors within a land use plan, the planner can achieve minimum exposures of critical receptors and land use categories.

Air quality for NO_X is not considered to be a critical consideration since total air quality levels are well below standards. In addition, variations in average regional concentration levels among the plans are relatively small (approximately 7%).

These results show that in many cases the planner can be neutral in his choice of a plan based on air quality considerations. In particular, these results indicate that in the presence of high background levels, total air quality levels are extremely insensitive to the choice of a plan, even when emissions resulting from alternative plans differ significantly. Thus when total pollutant concentrations are well below standards, the consideration of air quality is not necessarily a critical factor in choosing among alternative land use plans. For example, it is noted that in plans where total concentrations for SO_2, CO, and NO_X are well within ambient air quality standards, the planner can be relatively neutral in his choice of a plan, provided that he is concerned only with these specific pollutants.

The quantitative analysis of the plans was carried out by calculating various measures of impact. Table 9 summarizes the results by ordering the plans in terms of the Relative Ratio index (as defined in Section 2.2.3) for each individual pollutant. As noted previously, the Relative Ratio also indicates the percent variation among the plans for the specified impact measure.

As a result of the evaluation of plans in terms of single pollutant impacts, the ranking for TSP, SO_2, and NO_X was found to be (from best to worst) Plan 1, 1B, 1A, and 1C for nearly all choices of impact measure based on average exposures (in contrast to integrated exposure impacts). The ordering of plans for both CO and HC was found to depend strongly on the specific receptors impacted. However, on the basis of average CO exposures, Plan 1 was judged best generally for all receptors of interest. For HC, Plan 1 was judged best on the basis of impact on regional air quality considerations while Plan 1B was judged best on the basis of average population exposures (a result strongly influenced by the location of most residential areas in the western part of the Meadowlands).

The correlation between land uses (Figures 8 to 11) and regional air quality contours (Figures 13 to 32) showed generally that lowest average

TABLE 9

RELATIVE RANKING OF PLANS BY POLLUTANT ON BASIS OF QUANTITATIVE MEASURES OF IMPACT

Impact Measure	Plan Rank (Best to Worst)	TSP		SO_2		CO		HC		NO_x	
		Plan	(Ratio)[1]	Plan	(Ratio)	Plan	(Ratio)	Plan	(Ratio)	Plan	(Ratio)
Integrated and average total area exposure	1	1	(1.000)	1	(1.000)	1C	(1.000)	1	(1.000)	1	(1.000)
	2	1B	(1.021)	1B	(1.032)	1	(1.008)	1A	(1.005)	1B	(1.024)
	3	1A	(1.039)	1A	(1.059)	1A	(1.042)	1C	(1.006)	1A	(1.032)
	4	1C	(1.101)	1C	(1.149)	1B	(1.054)	1B	(1.007)	1C	(1.071)
Integrated population exposure	1	1C	(1.0)	1C	(1.0)	1C	(1.0)	1C	(1.000)	1C	(1.000)
	2	1	(16.0)	1	(15.4)	1	(17.3)	1	(17.3)	1	(16.3)
	3	1A	(47.9)	1A	(47.4)	1A	(51.4)	1A	(50.7)	1A	(48.9)
	4	1B	(51.9)	1B	(50.3)	1B	(59.1)	1B	(53.8)	1B	(52.5)
Average population exposure	1	1	(1.000)	1	(1.000)	1	(1.000)	1B	(1.000)	1	(1.000)
	2	1B	(1.015)	1B	(1.038)	1C	(1.027)	1	(1.021)	1B	(1.014)
	3	1A	(1.081)	1A	(1.123)	1B	(1.053)	1C	(1.070)	1A	(1.088)
	4	1C	(1.128)	1C	(1.174)	1A	(1.054)	1A	(1.085)	1C	(1.112)
Integrated open space area exposure	1	1C	(1.000)	1C	(1.000)	1C	(1.000)	1C	(1.000)	1C	(1.000)
	2	1B	(1.853)	1B	(1.759)	1A	(2.137)	1B	(2.000)	1B	(1.875)
	3	1A	(1.920)	1A	(1.825)	1B	(2.186)	1A	(2.036)	1A	(1.931)
	4	1	(3.271)	1	(3.094)	1	(3.694)	1	(3.578)	1	(3.059)
Average open space area exposure	1	1	(1.000)	1	(1.000)	1C	(1.000)	1B	(1.000)	1	(1.000)
	2	1B	(1.010)	1B	(1.014)	1	(1.017)	1	(1.003)	1B	(1.083)
	3	1A	(1.044)	1A	(1.049)	1A	(1.046)	1A	(1.015)	1A	(1.111)
	4	1C	(1.110)	1C	(1.174)	1B	(2.074)	1C	(1.018)	1C	(1.176)
Integrated students exposure	1	1	(1.000)	1	(1.000)	1	(1.000)	1	(1.000)	1	(1.000)
	2	1A	(2.538)	1A	(2.606)	1A	(2.466)	1A	(2.496)	1A	(2.564)
	3	1B	(4.559)	1B	(4.699)	1B	(4.772)	1B	(4.484)	1B	(4.624)
	4		--(2)		--(2)		--(2)		--(2)		--(2)
Average students exposure	1	1	(1.000)	1	(1.000)	1	(1.000)	1	(1.000)	1	(1.000)
	2	1B	(1.031)	1B	(1.056)	1A	(1.064)	1B	(1.007)	1B	(1.039)
	3	1A	(1.095)	1A	(1.124)	1B	(1.072)	1A	(1.077)	1A	(1.107)
	4		--(2)		--(2)		--(2)		--(2)		--(2)
Integrated residential exposure	1	1C	(1.000)	1C	(1.000)	1C	(1.000)	1C	(1.000)	1C	(1.000)
	2	1	(4.894)	1	(4.732)	1	(5.382)	1	(5.293)	1	(4.996)
	3	1A	(13.727)	1A	(13.535)	1A	(14.932)	1A	(14.388)	1A	(13.994)
	4	1B	(16.576)	1B	(16.329)	1B	(18.902)	1B	(17.207)	1B	(16.781)
Average residential exposure	1	1	(1.000)	1	(1.000)	1	(1.000)	1B	(1.000)	1	(1.000)
	2	1B	(1.008)	1B	(1.031)	1C	(1.030)	1	(1.030)	1B	(1.003)
	3	1A	(1.062)	1A	(1.083)	1A	(1.043)	1A	(1.060)	1A	(1.060)
	4	1C	(1.132)	1C	(1.171)	1B	(1.049)	1C	(1.078)	1C	(1.109)
Integrated commercial and industrial area exposure	1	1C	(1.000)	1C	(1.000)	1C	(1.000)	1C	(1.000)	1C	(1.000)
	2	1A	(1.984)	1A	(1.902)	1A	(2.181)	1A	(2.125)	1A	(2.036)
	3	1B	(2.115)	1B	(2.064)	1B	(2.481)	1B	(2.378)	1B	(2.258)
	4	1	(2.235)	1	(2.131)	1	(2.497)	1	(2.513)	1	(2.333)
Average commercial and industrial area exposure	1	1	(1.000)	1	(1.000)	1C	(1.000)	1C	(1.000)	1	(1.000)
	2	1B	(1.032)	1A	(1.048)	1	(1.007)	1A	(1.003)	1A	(1.026)
	3	1A	(1.037)	1B	(1.058)	1A	(1.030)	1	(1.013)	1B	(1.057)
	4	1C	(1.105)	1C	(1.164)	1B	(1.093)	1B	(1.047)	1C	(1.063)

(1) Ratio of best plan is defined as unity; other ratios represent the relative values of the exposure parameter.

(2) Plan 1C has no student population specified.

regional pollutant concentration levels for TSP, SO_2, and NO_X are achieved by those plans having the least percentage of land use devoted to manufacturing, and that lowest levels for CO result from plans having the least vehicle trip miles. Similarly, it was demonstrated that the location of manufacturing land use within a plan is the dominant influence on TSP, SO_2, and NO_X air quality contours, and that the location of roadways within a plan is the dominant influence on CO air quality contours.

In addition, the specific correlations between population density (Figures 33 to 36) and air quality contours generally showed that those plans having the least pollutant impact on population were those having the most population located in the western portions of the region (or more specifically, in those regions of the plan where background concentration levels are lowest). As indicated by the impact parameters listed in Table 9, Plans 1 and 1B generally ranked highest in terms of impact on population - Plan 1 because of its lower regional average concentrations and Plan 1B because of its better location of residential areas within the plan.

Finally, it was observed that all land use categories other than manufacturing and transportation have a significantly smaller impact on regional air quality. This is indicated dramatically in Table 4 by the differences in emission rates for the various land use categories. Thus in the presence of high background levels, such land uses can in general be located rather arbitrarily within the planning region without any significant impact on regional concentration levels or air quality contours. However, the relative location of such land uses within a plan can cause a significant change in the degree of impact on critical receptors and land use activities. Consequently, the consideration of air pollution in the planning process is important not only as a means to long-term air quality improvement but also as a means of reducing impacts on sensitive receptors.

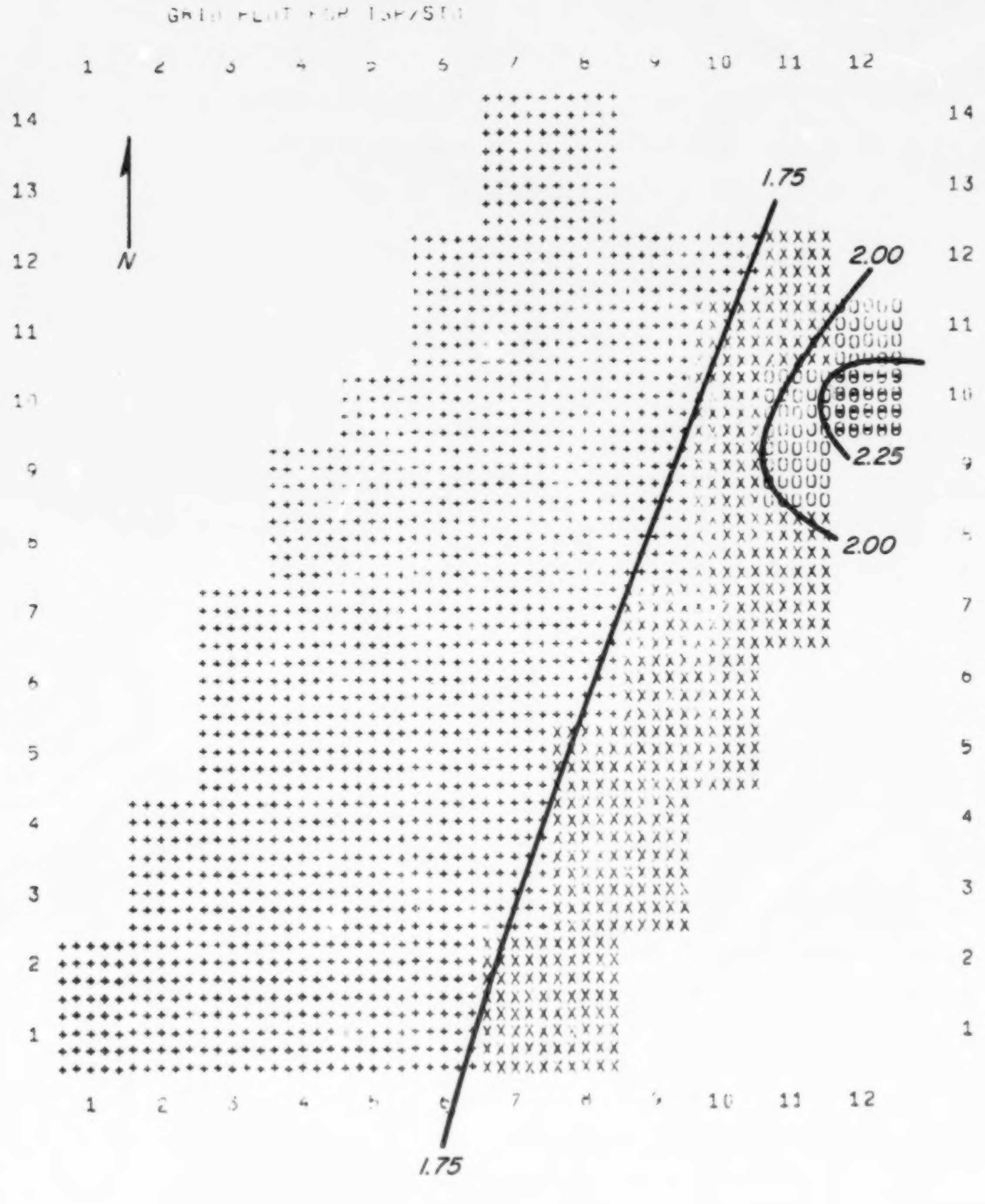


Figure 13 Air Quality Contours for Particulates for Plan 1, Expressed as the Ratio of Air Quality/Air Quality Standard

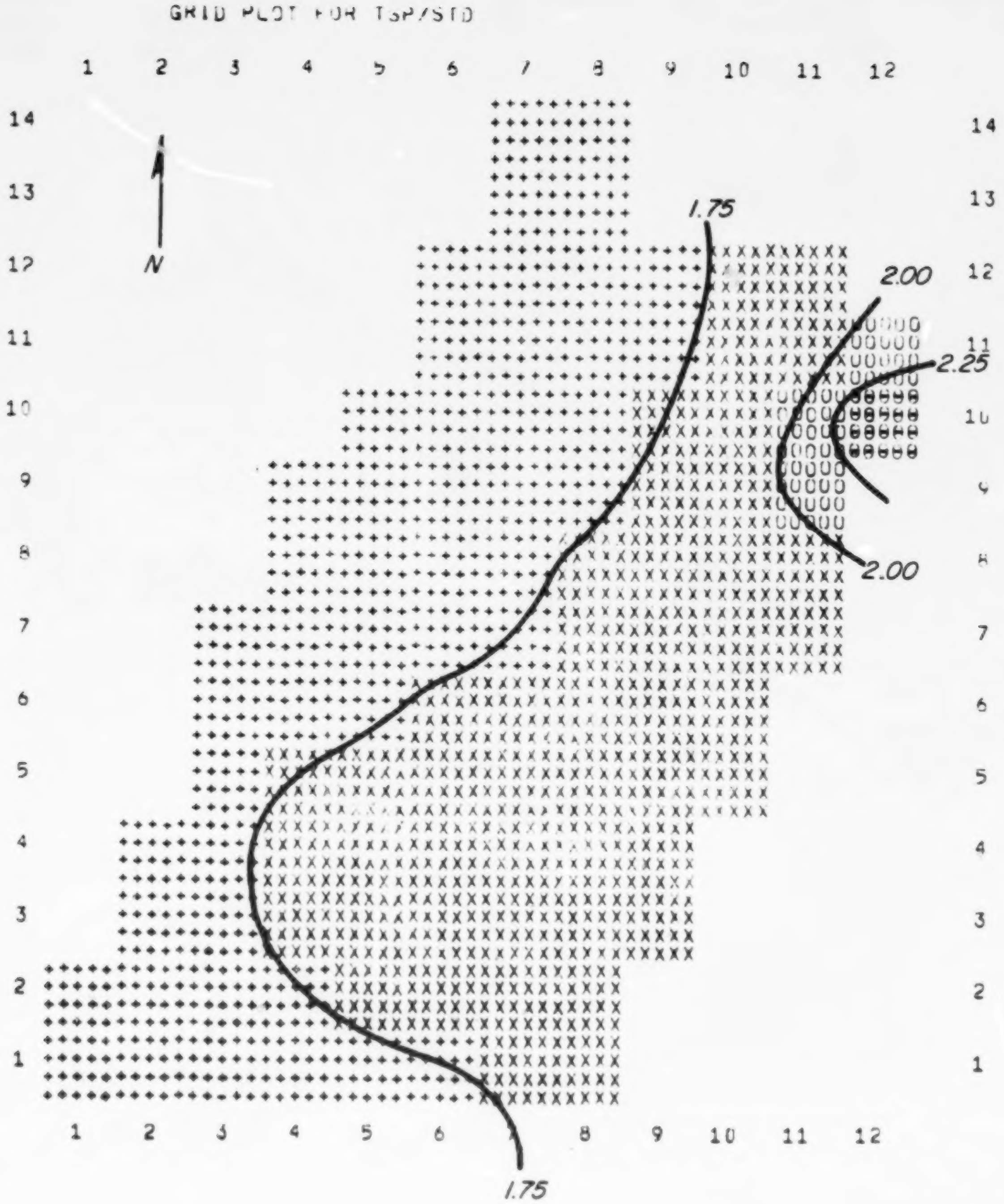

GRID PLOT FOR TSP/STD
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
1.75
2.00
2.25
2.00
1.75

Figure 14 Air Quality Contours for Particulates for Plan 1A, Expressed as the Ratio of Air Quality/Air Quality Standard

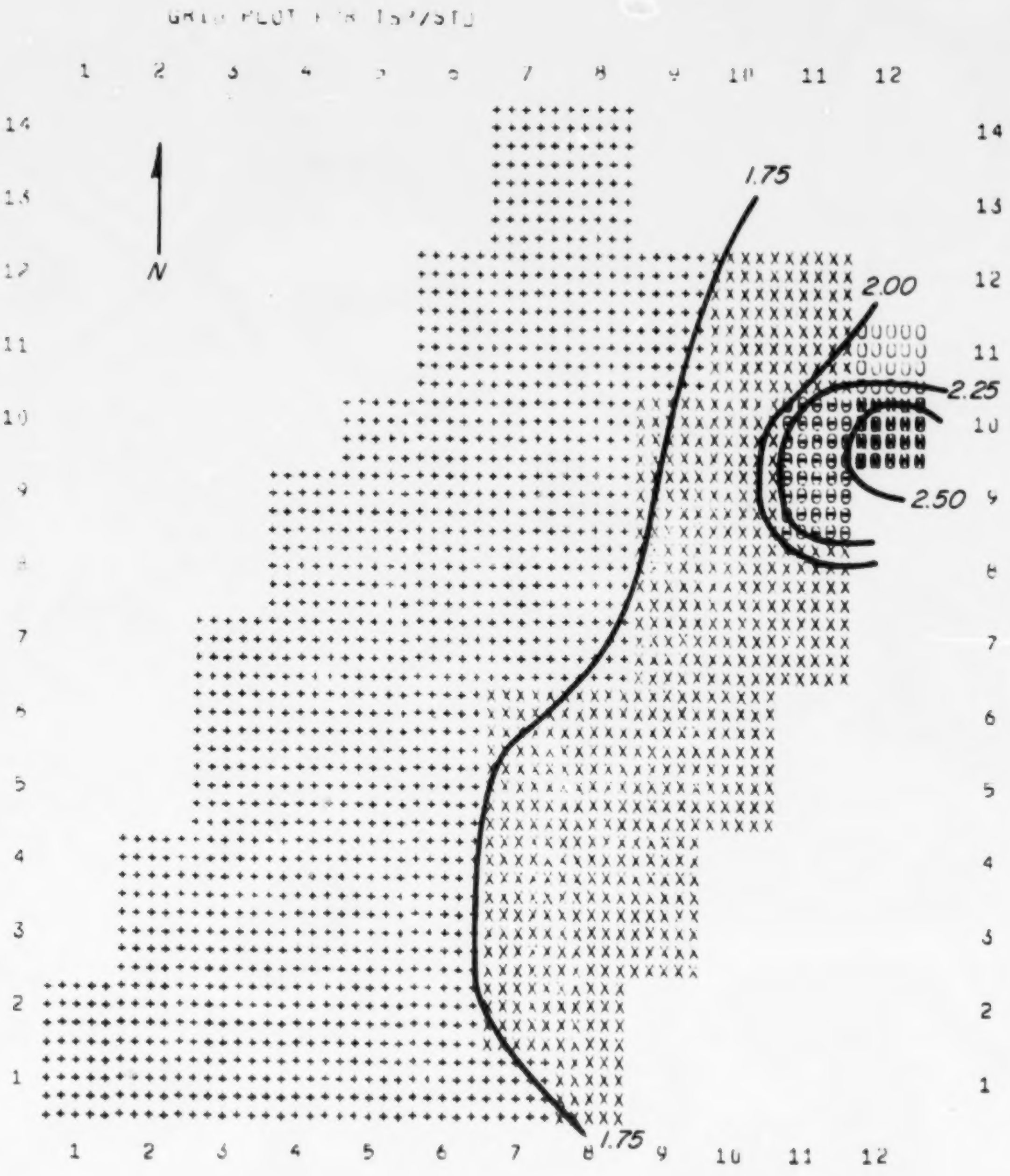

GRID PLOT FOR TSP/STD
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
1.75
2.00
2.25
2.50
1.75

Figure 15 Air Quality Contours for Particulates for Plan 1B, Expressed as the Ratio of Air Quality/Air Quality Standard

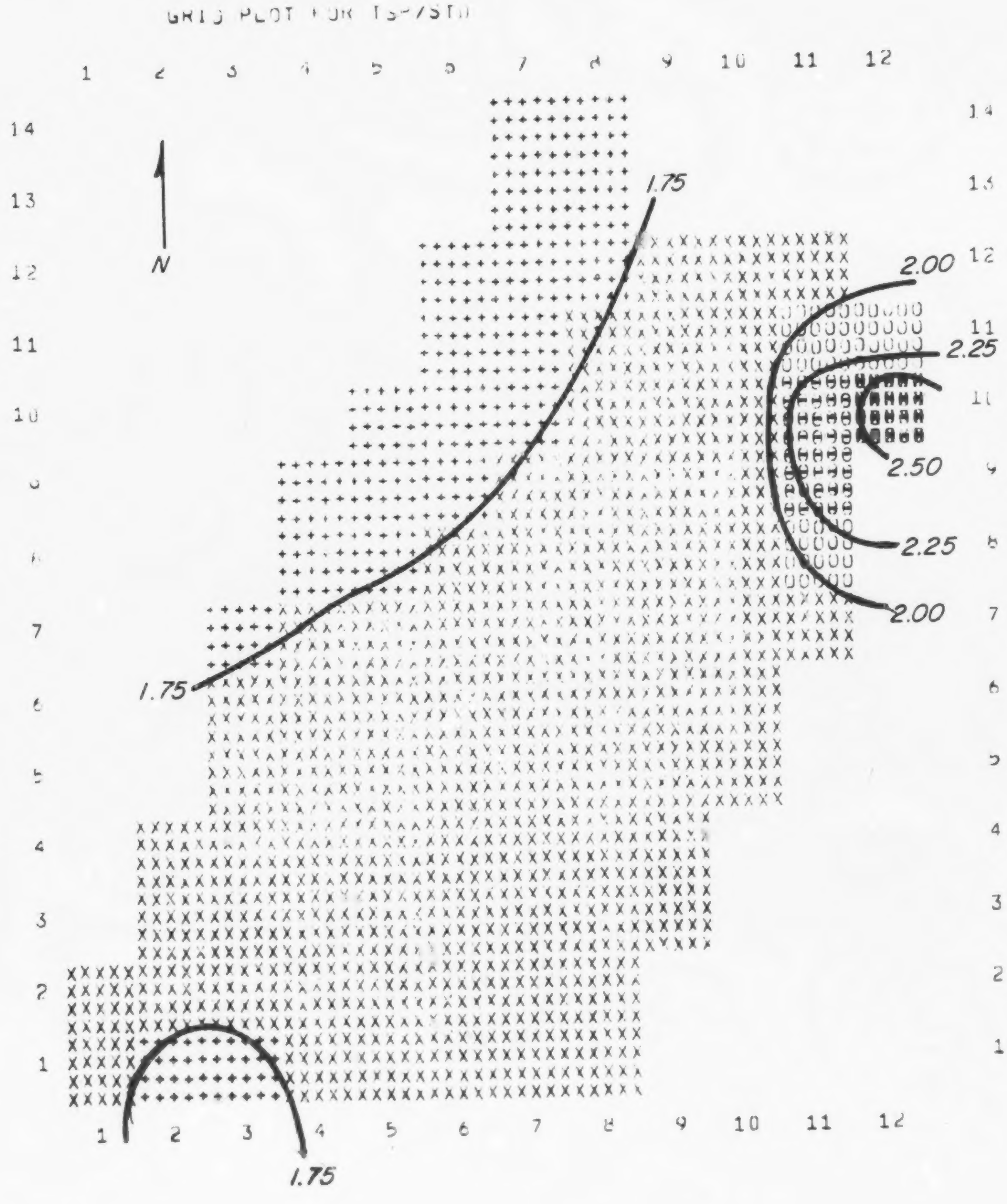

GRID PLOT FOR TSP/STD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
N
1.75
2.00
2.25
2.50

Figure 16 Air Quality Contours for Particulates for Plan 1C, Expressed as the Ratio of Air Quality/Air Quality Standard

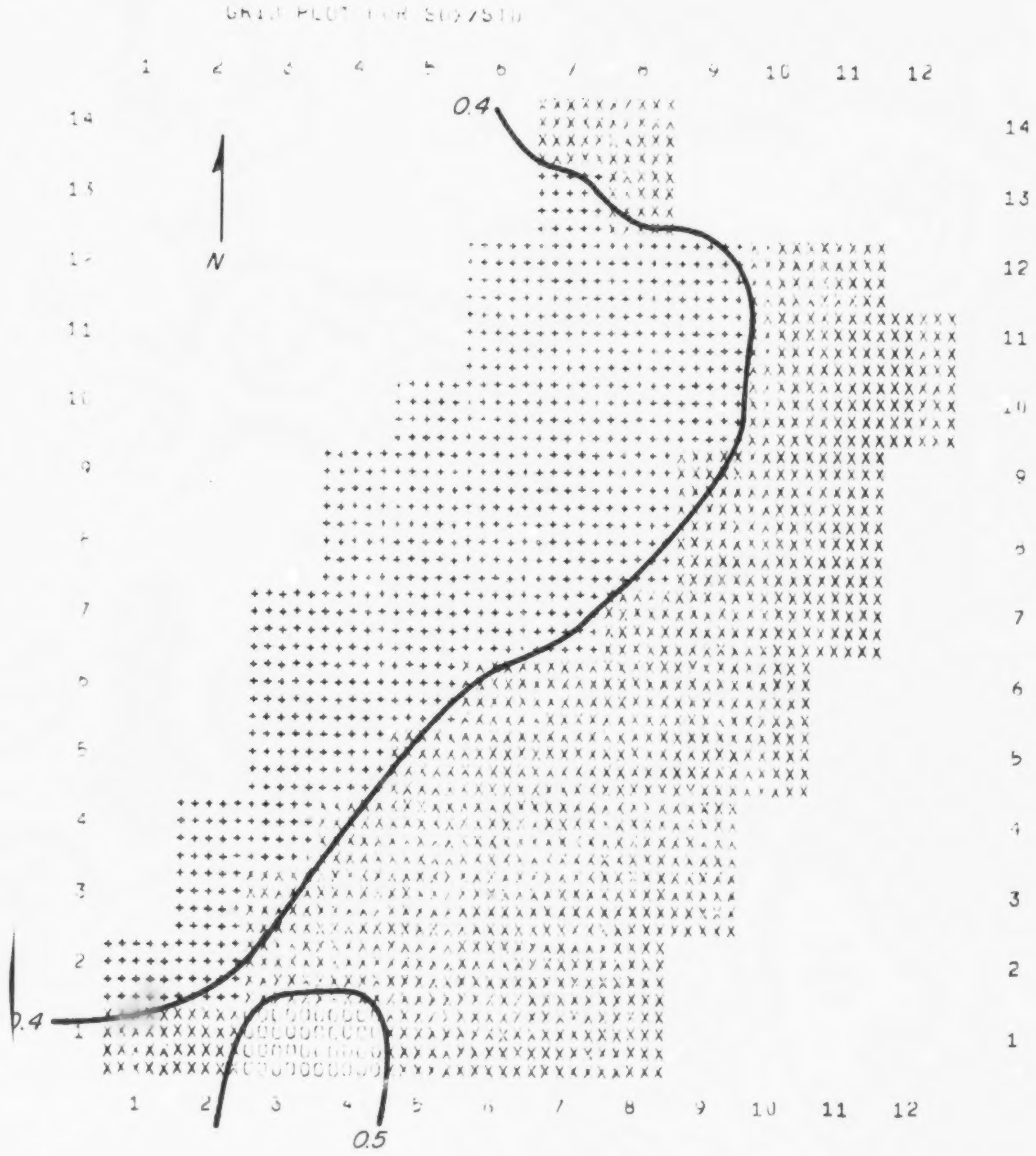

GRID PLOT FOR SOX/STD
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
0.4
0.4
0.5

Figure 17 Air Quality Contours for Sulfur Oxides for Plan 1, Expressed as the Ratio of Air Quality/Air Quality Standard

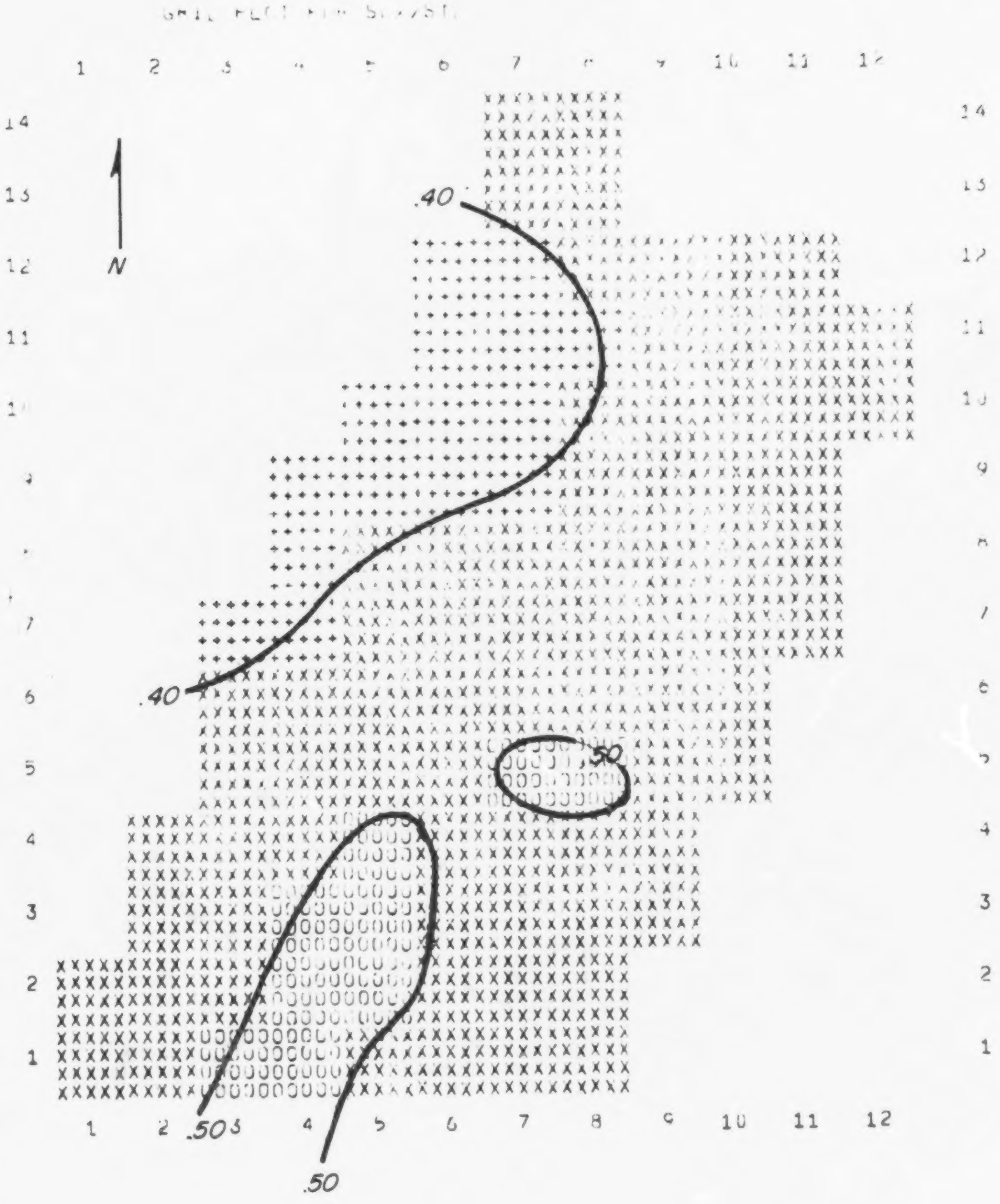

GRID PLOT FOR SOX/ST
N
.40
.40
.50
.50
.50
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1

Figure 18 Air Quality Contours for Sulfur Oxides for Plan 1A, Expressed as the Ratio of Air Quality/Air Quality Standard

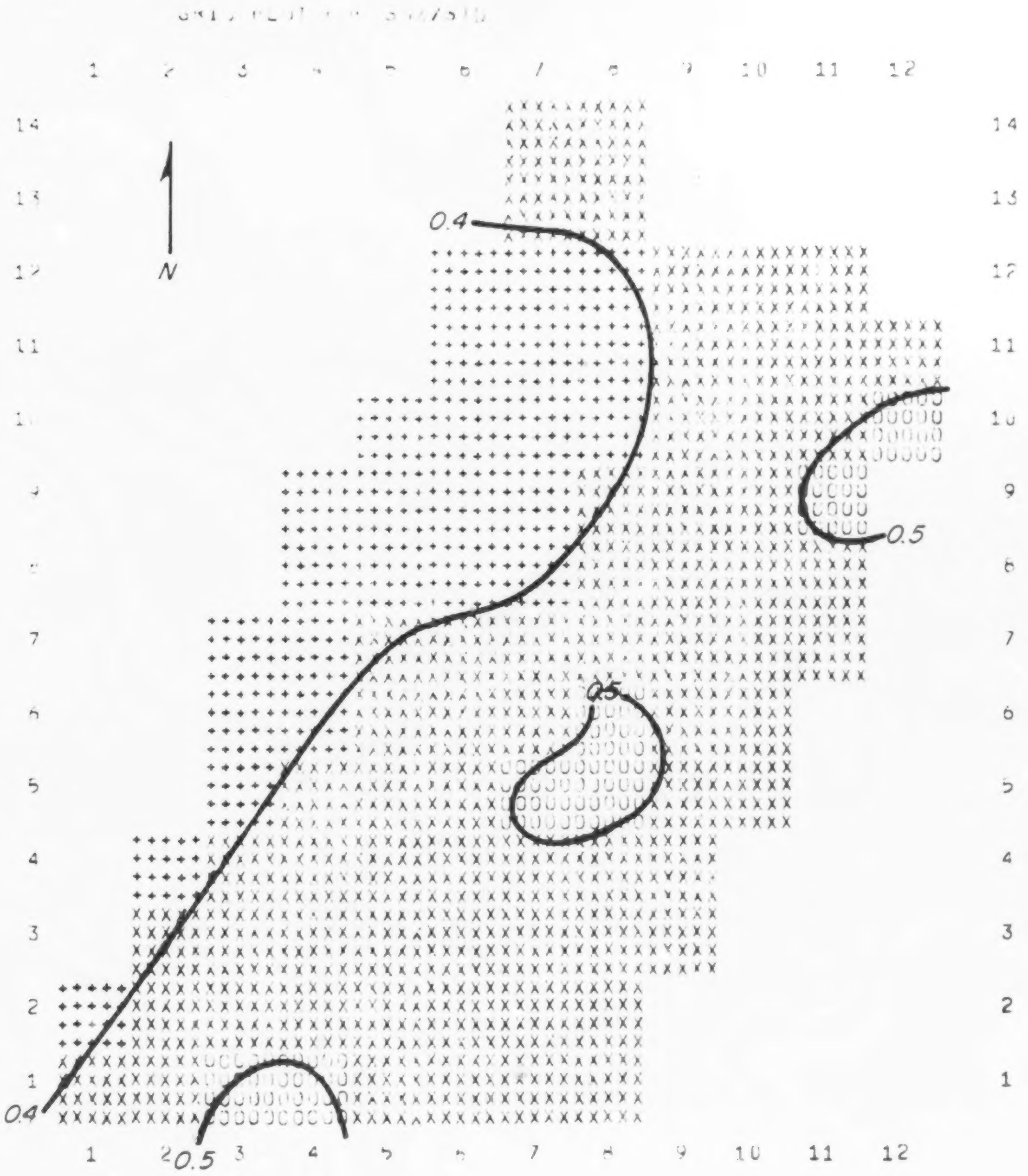

N
0.4
0.4
0.5
0.5
0.5
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1

Figure 19 Air Quality Contours for Sulfur Oxides for Plan 1B, Expressed as the Ratio of Air Quality/Air Quality Standard

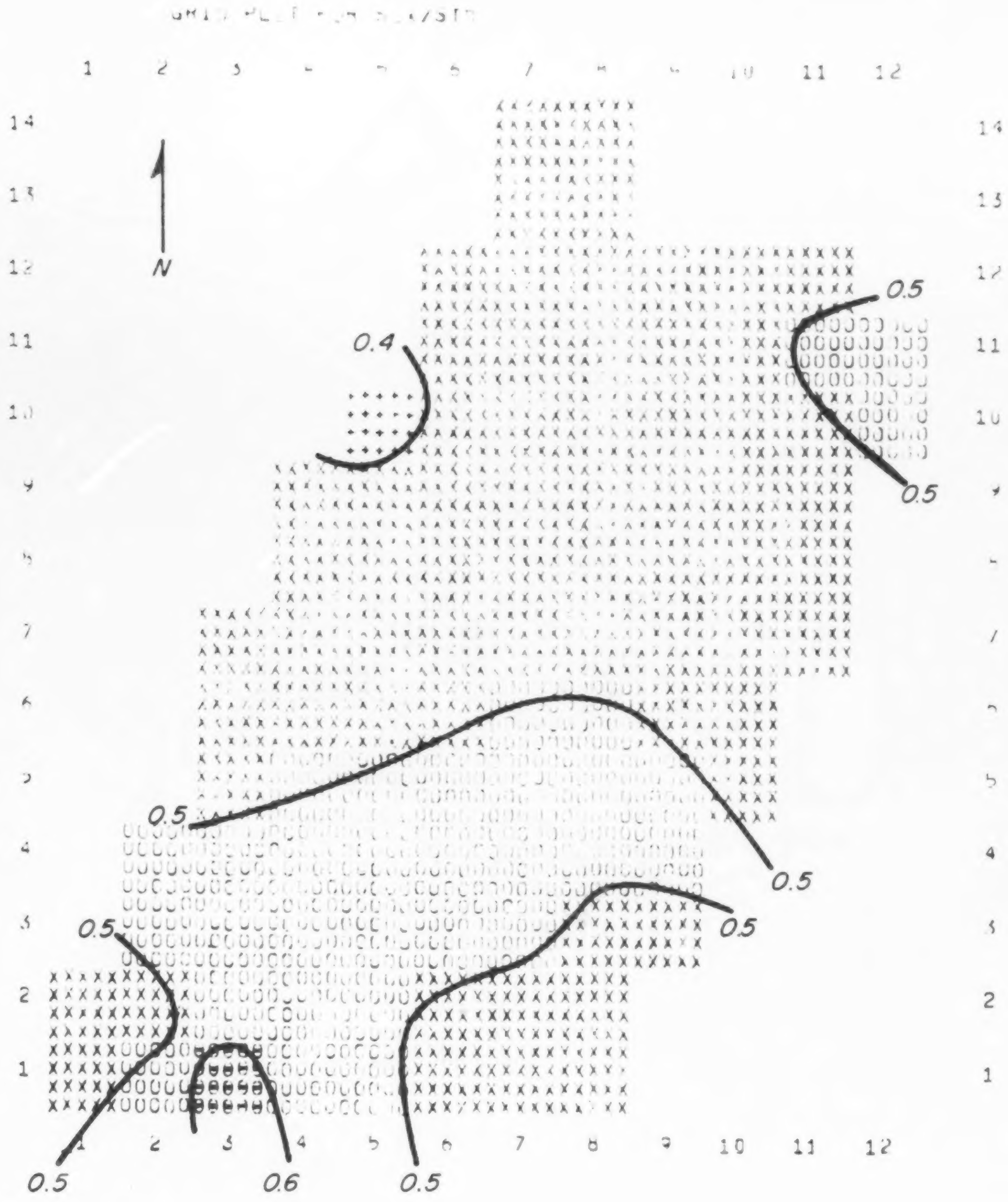

N
0.4
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.6
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 20 Air Quality Contours for Sulfur Oxides for Plan 1C, Expressed as the Ratio of Air Quality/Air Quality Standard

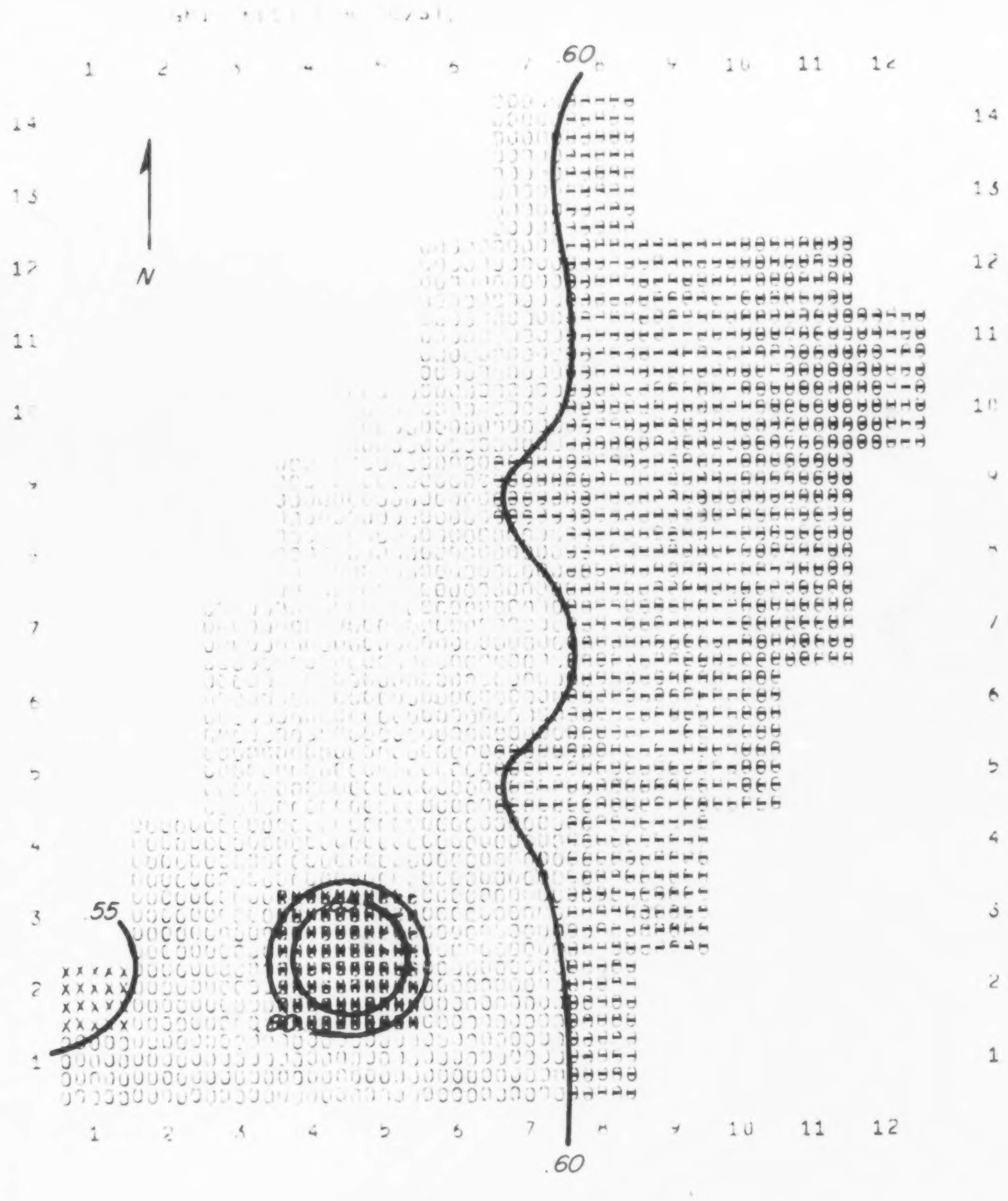
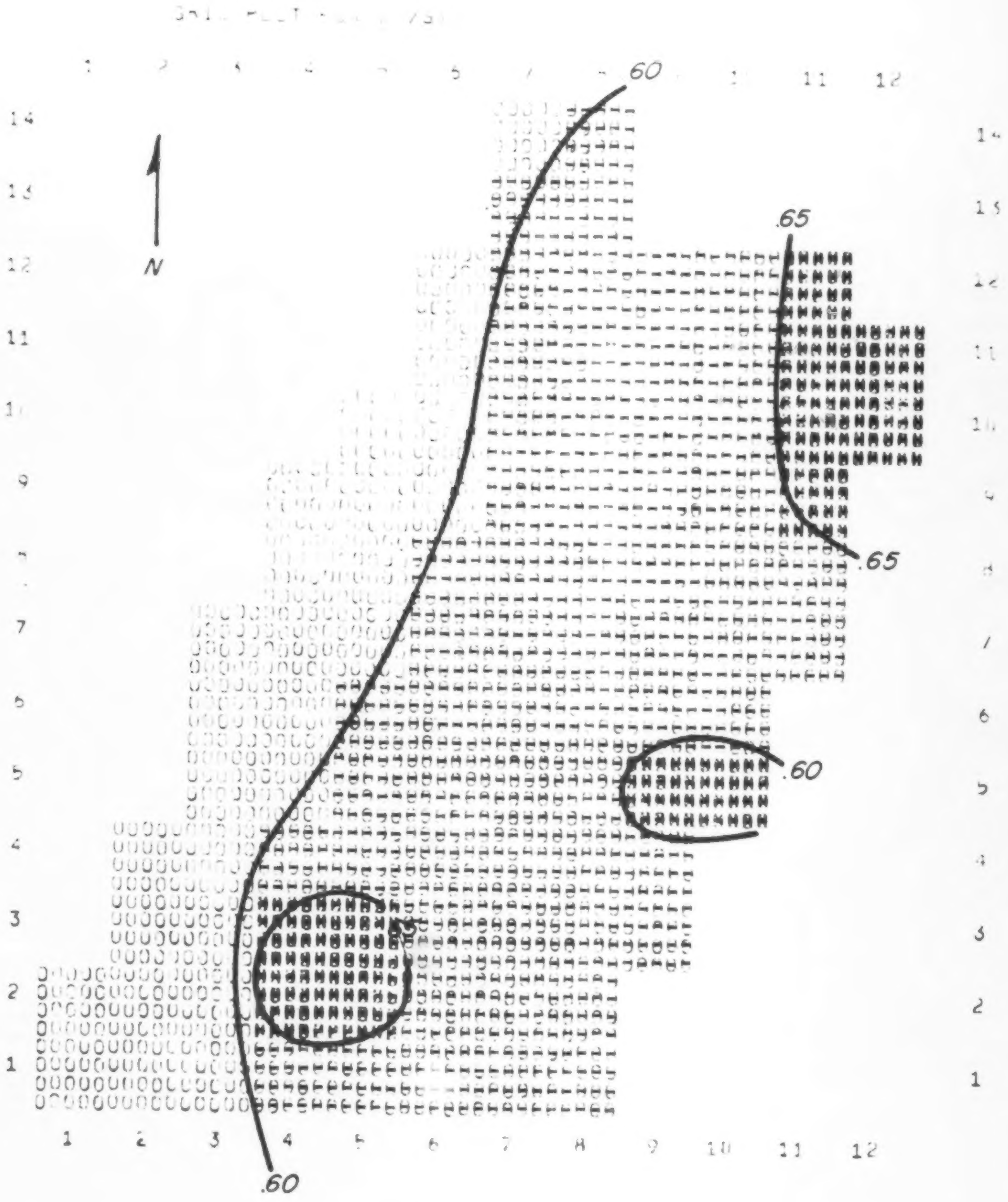

1
2
3
4
5
6
7
8
9
10
11
12
14
13
12
11
10
9
8
7
6
5
4
3
2
1
N
.60
.55
.80
.60

Figure 21 Air Quality Contours for Carbon Monoxide for Plan 1, Expressed as the Ratio of Air Quality/Air Quality Standard



60
.65
.65
.60
.60
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 22 Air Quality Contours for Carbon Monoxide for Plan 1A, Expressed as the Ratio of Air Quality/Air Quality Standard

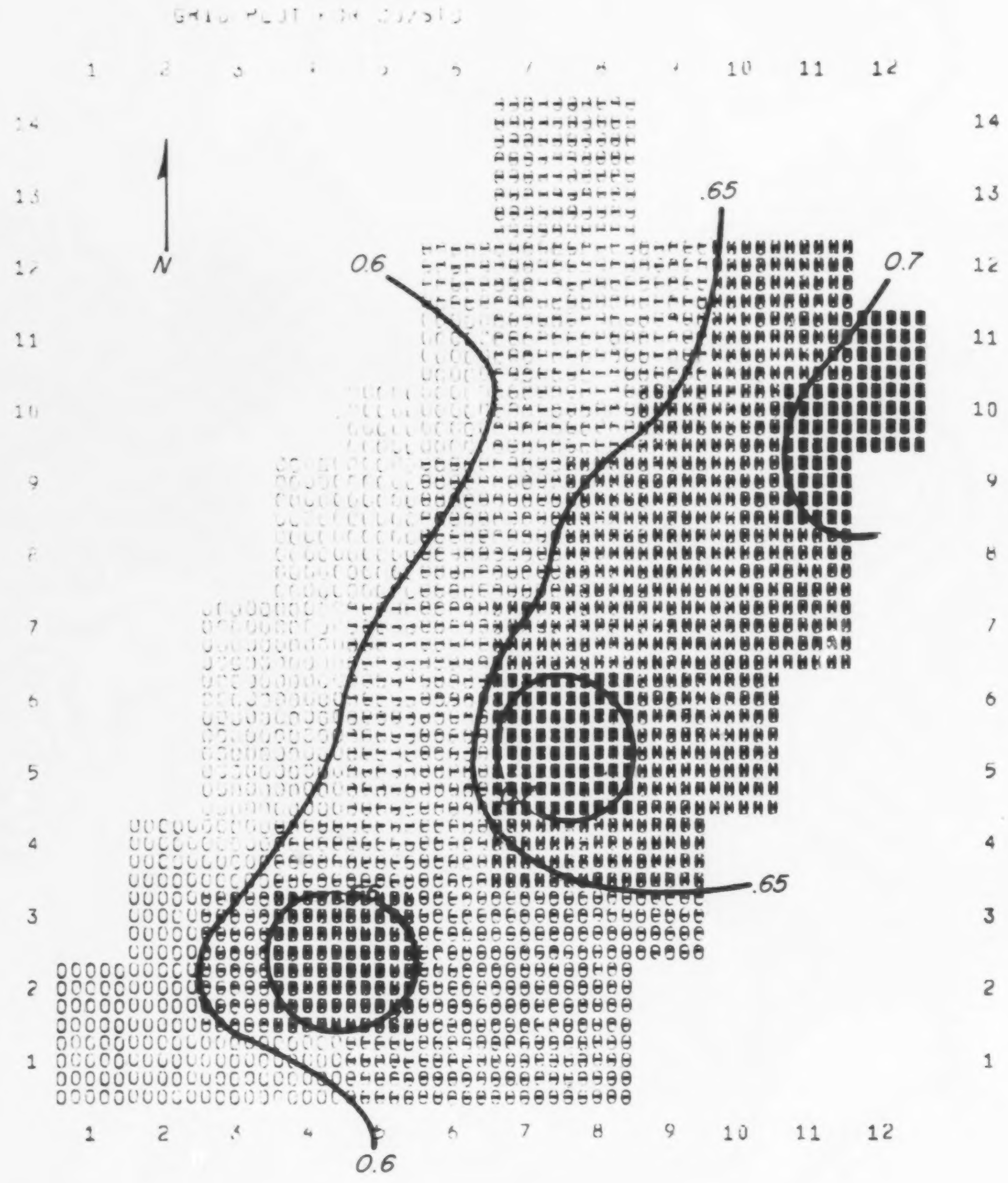

GRID PLOT FOR CO/STD
N
0.6
.65
0.7
.65
0.6
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1

Figure 23 Air Quality Contours for Carbon Monoxide for Plan 1B, Expressed as the Ratio of Air Quality/Air Quality Standard

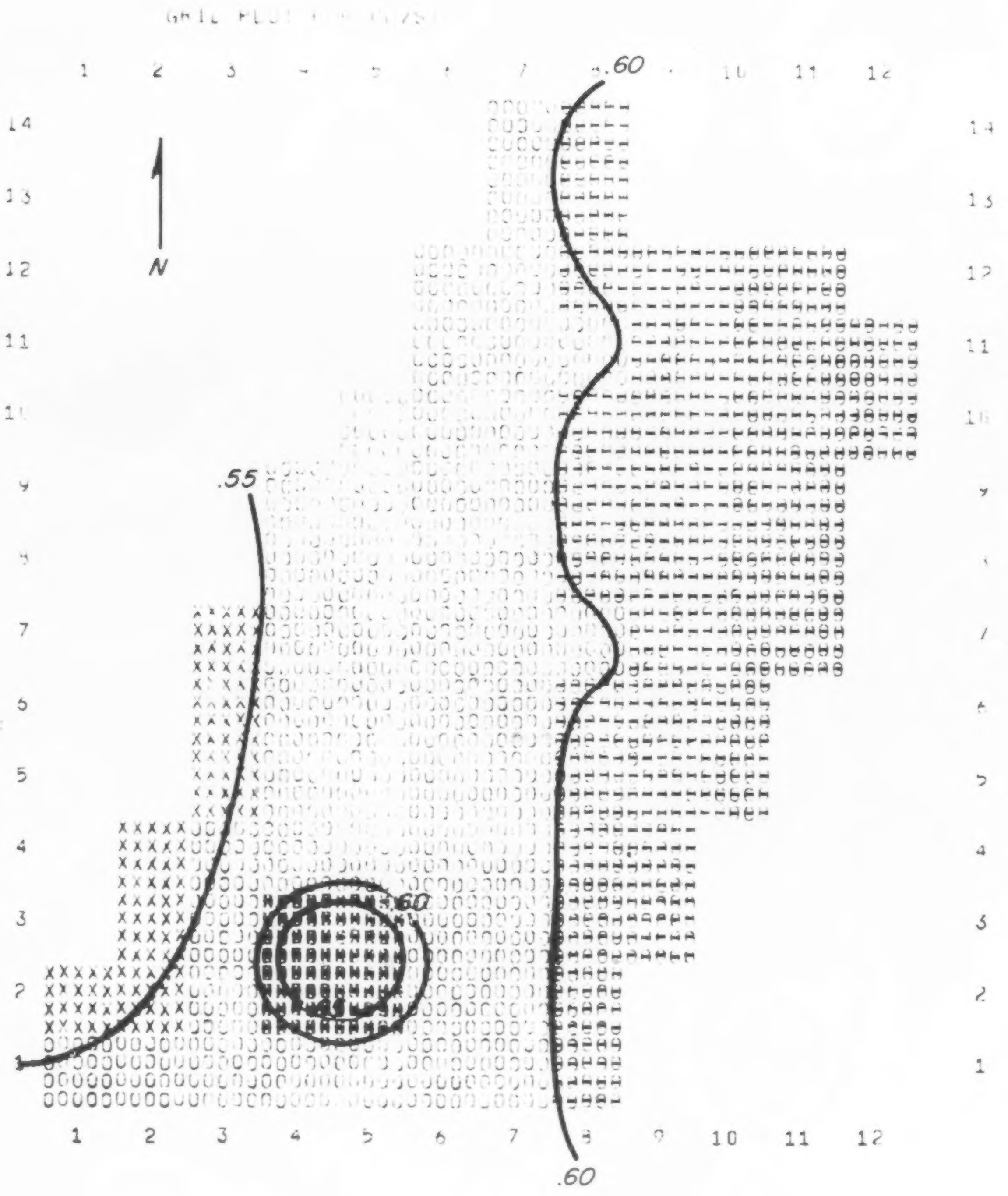
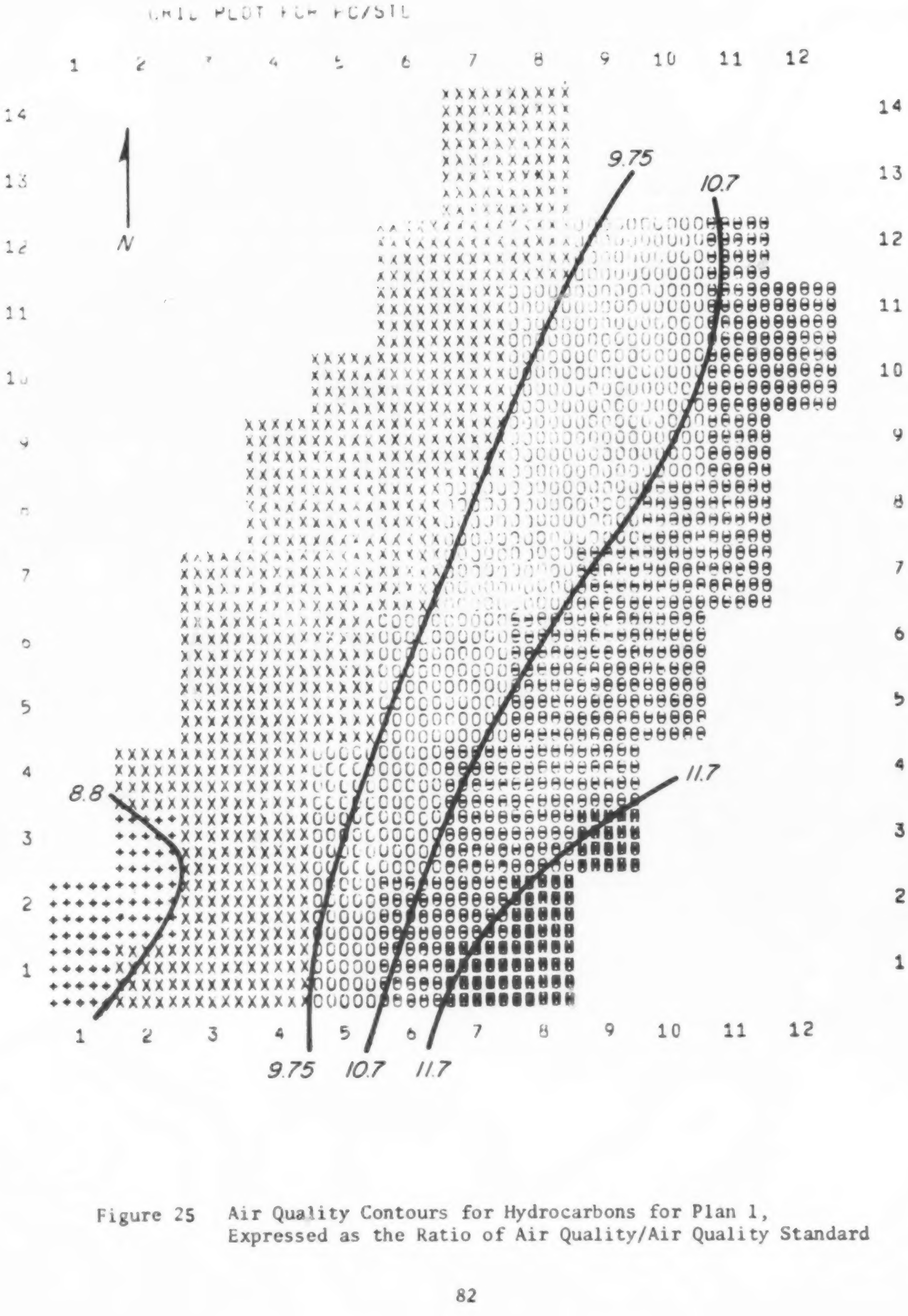

GRID PLOT
N
.55
.60
.60
.60
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1

Figure 24 Air Quality Contours for Carbon Monoxide for Plan 1C, Expressed as the Ratio of Air Quality/Air Quality Standard



GRID PLOT FOR HC/STD
1
2
3
4
5
6
7
8
9
10
11
12
14
13
12
11
10
9
8
7
6
5
4
3
2
1
N
9.75
10.7
11.7
8.8

Figure 25 Air Quality Contours for Hydrocarbons for Plan 1, Expressed as the Ratio of Air Quality/Air Quality Standard

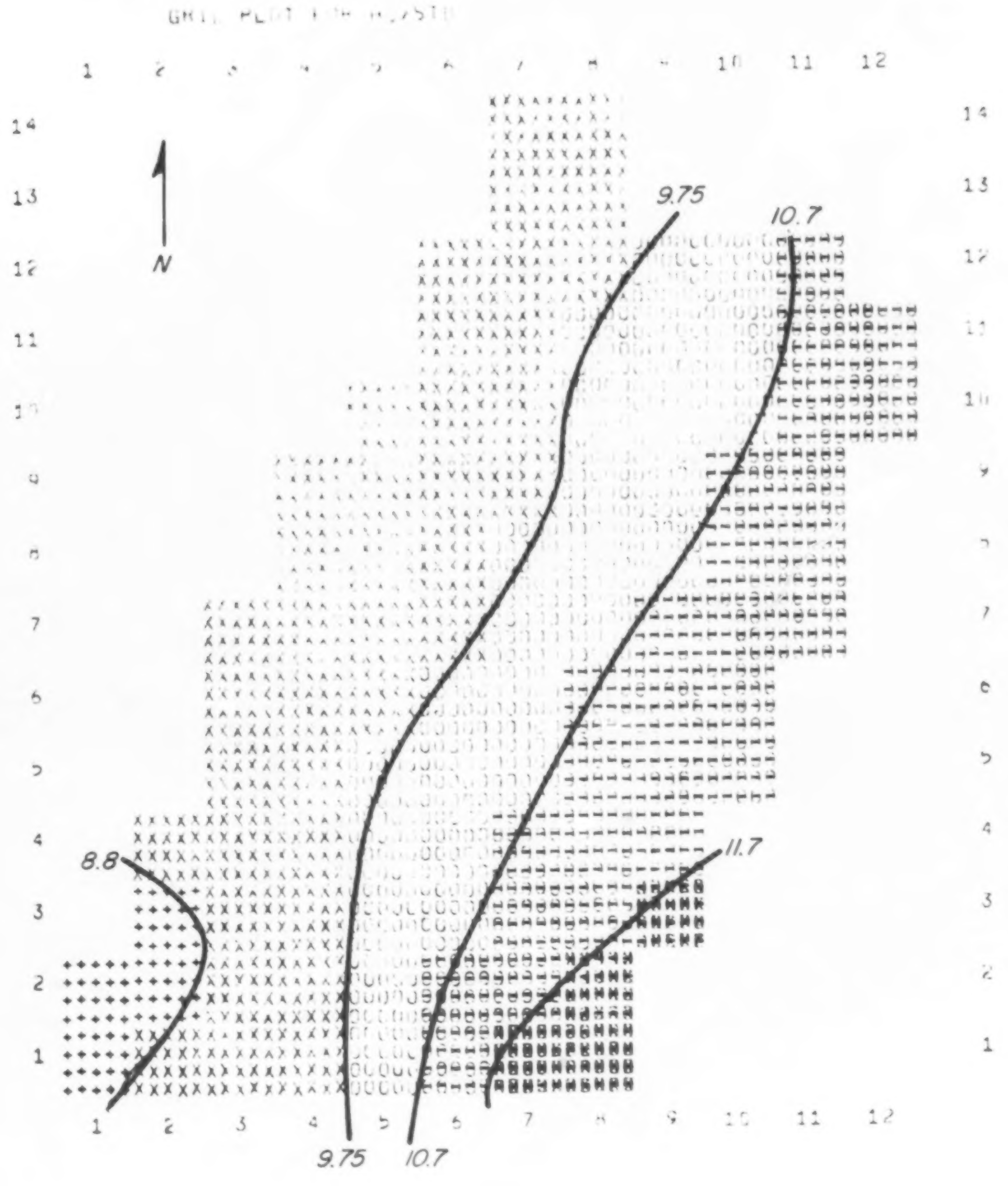

GRID PLOT FOR HC/STD
N
8.8
9.75
10.7
11.7
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 26 Air Quality Contours for Hydrocarbons for Plan 1A, Expressed as the Ratio of Air Quality/Air Quality Standard

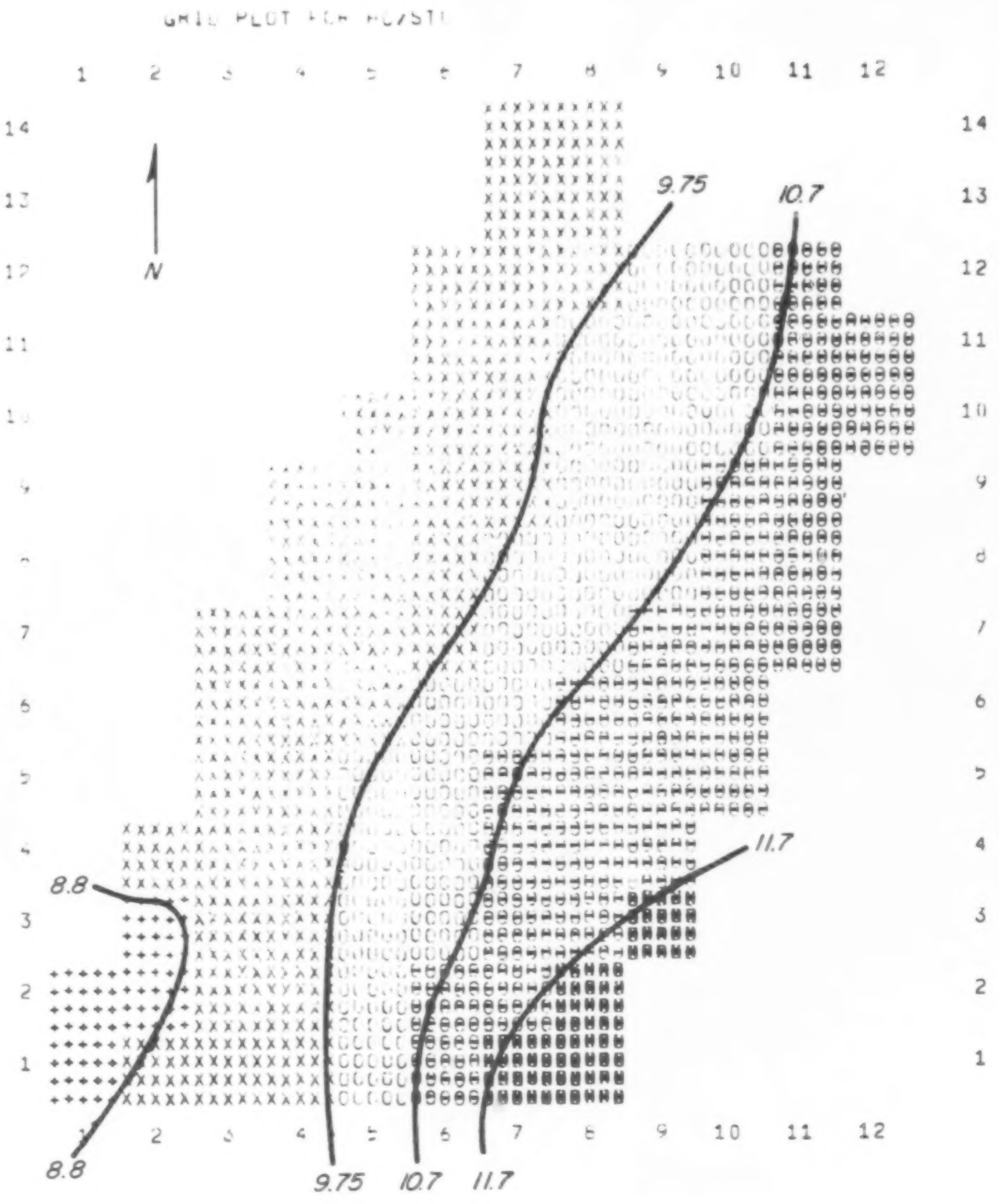

GRID PLOT FOR HC/STD
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
8.8
9.75
10.7
11.7

Figure 27 Air Quality Contours for Hydrocarbons for Plan 1B, Expressed as the Ratio of Air Quality/Air Quality Standard

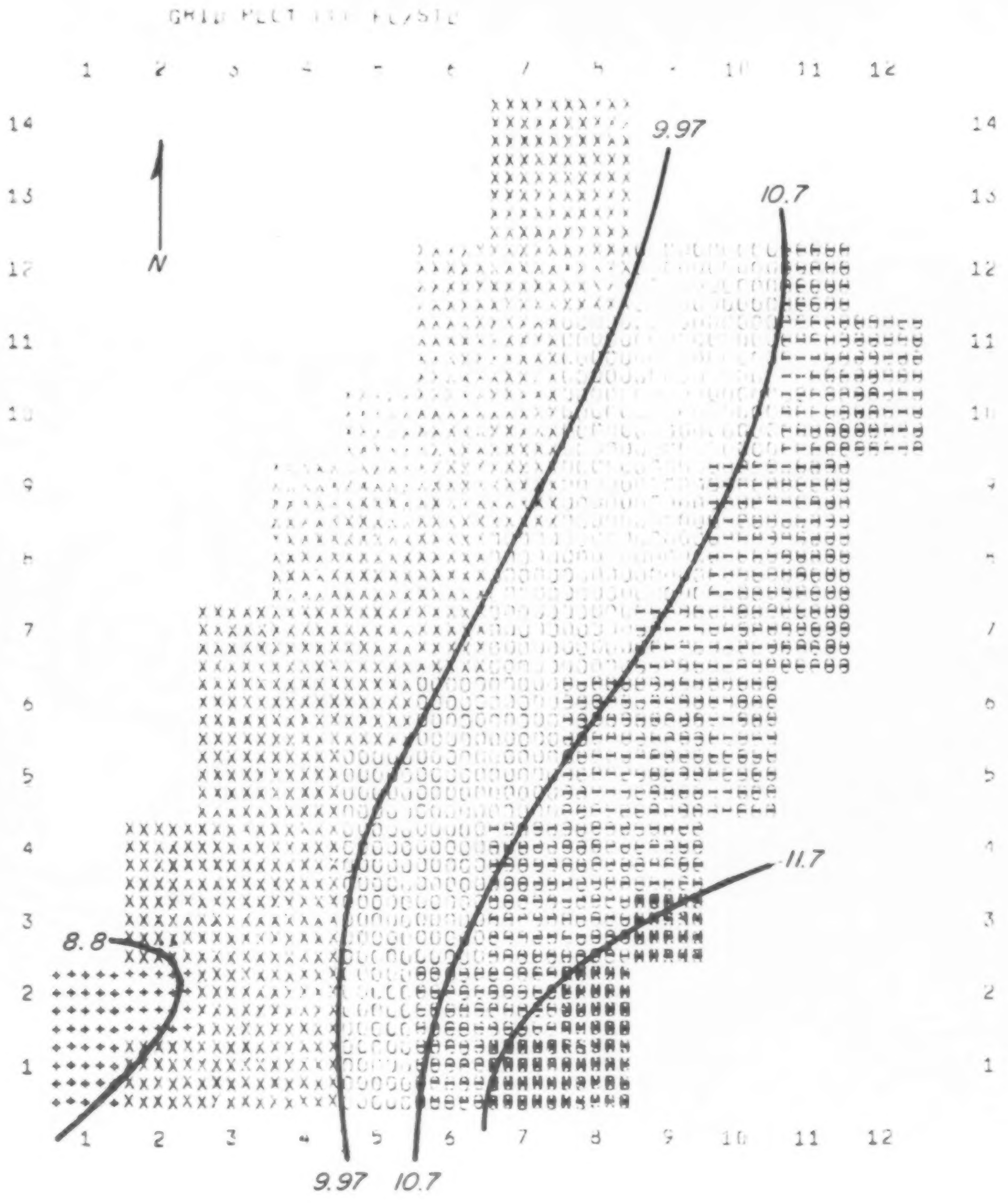

N
9.97
10.7
11.7
8.8
9.97
10.7
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 28 Air Quality Contours for Hydrocarbons for Plan 1C, Expressed as the Ratio of Air Quality/Air Quality Standard

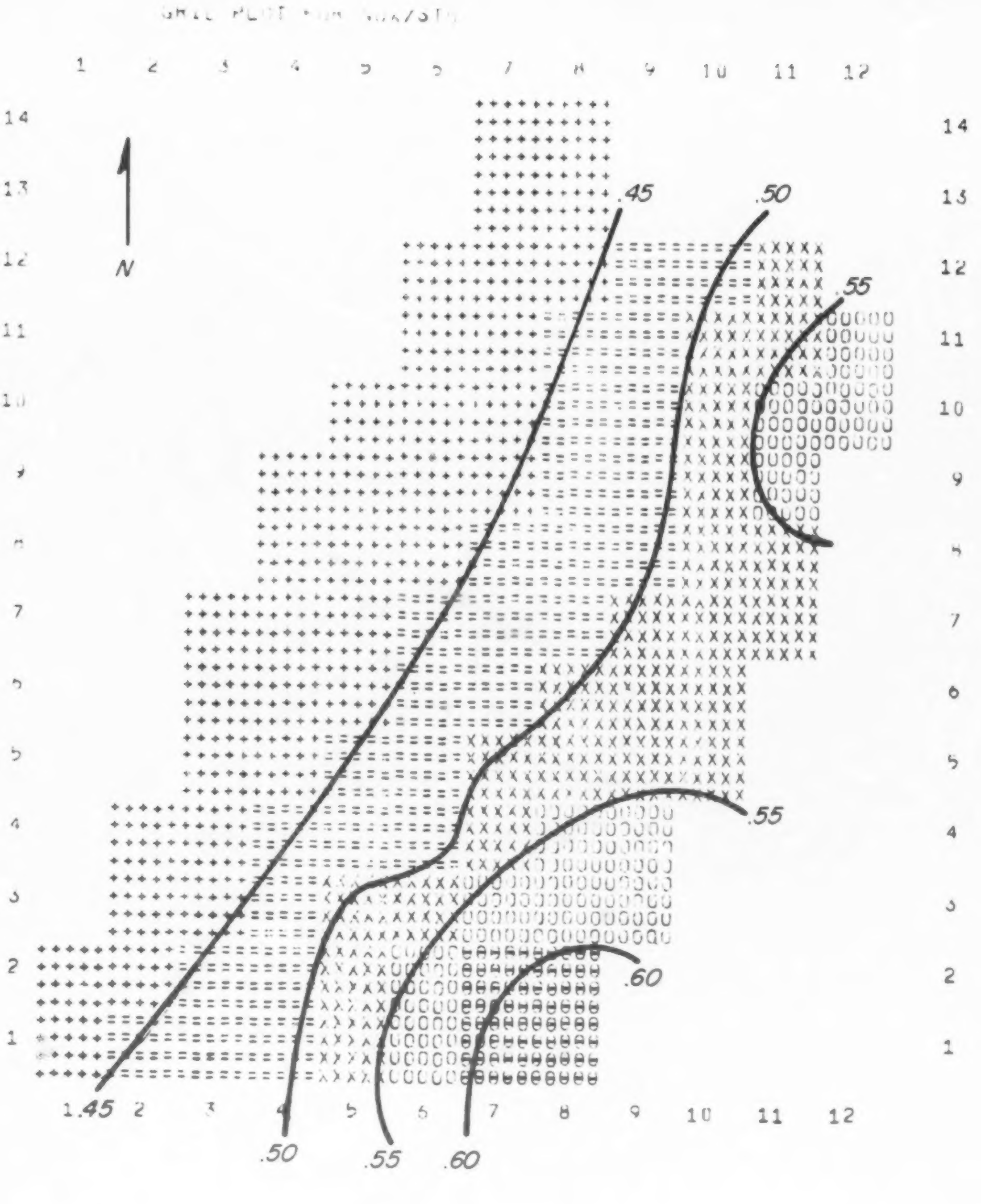

GRID PLOT FOR NOX/STD
N
.45
.50
.55
.60
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7 8 9 10 11 12 13 14

Figure 29 Air Quality Contours for Nitrogen Oxides for Plan 1, Expressed as the Ratio of Air Quality/Air Quality Standard

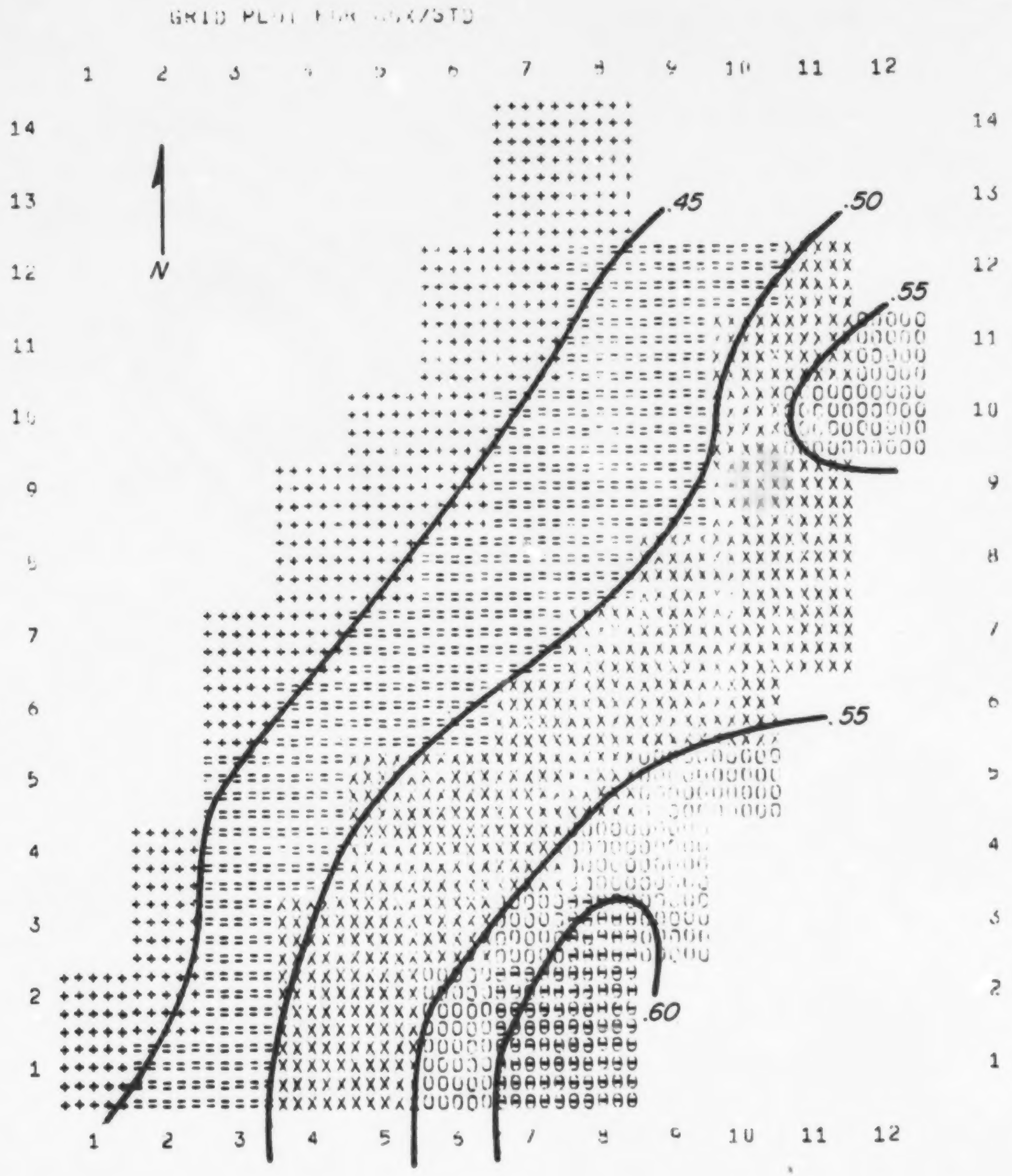

GRID PLOT FOR NOX/STD
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
.45
.50
.55
.55
.60

Figure 30 Air Quality Contours for Nitrogen Oxides for Plan 1A, Expressed as the Ratio of Air Quality/Air Quality Standard

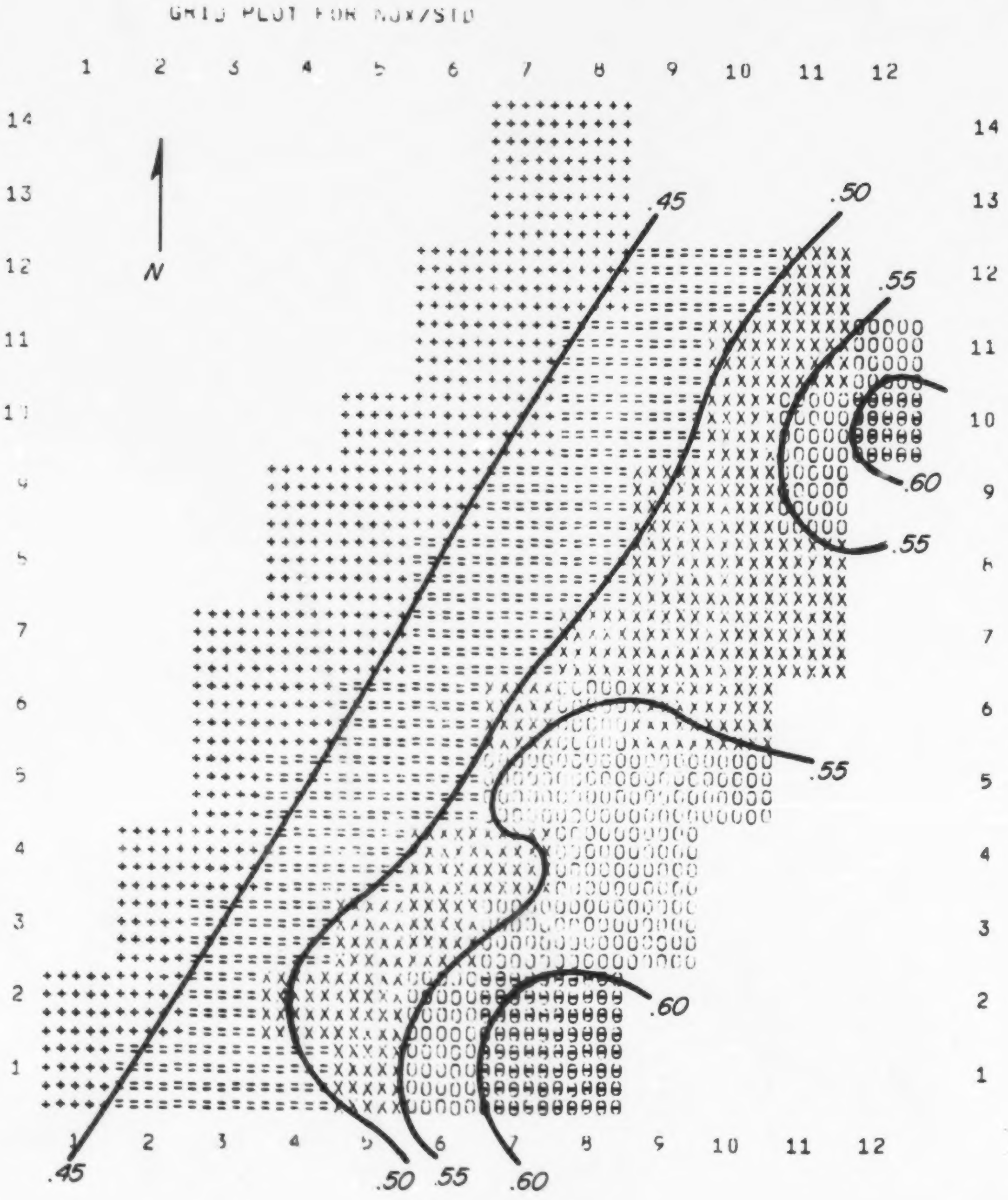

GRID PLOT FOR NOX/STD
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
.45
.50
.55
.60
.55
.60
.55
.45
.50
.55
.60

Figure 31 Air Quality Contours for Nitrogen Oxides for Plan 1B, Expressed as the Ratio of Air Quality/Air Quality Standard

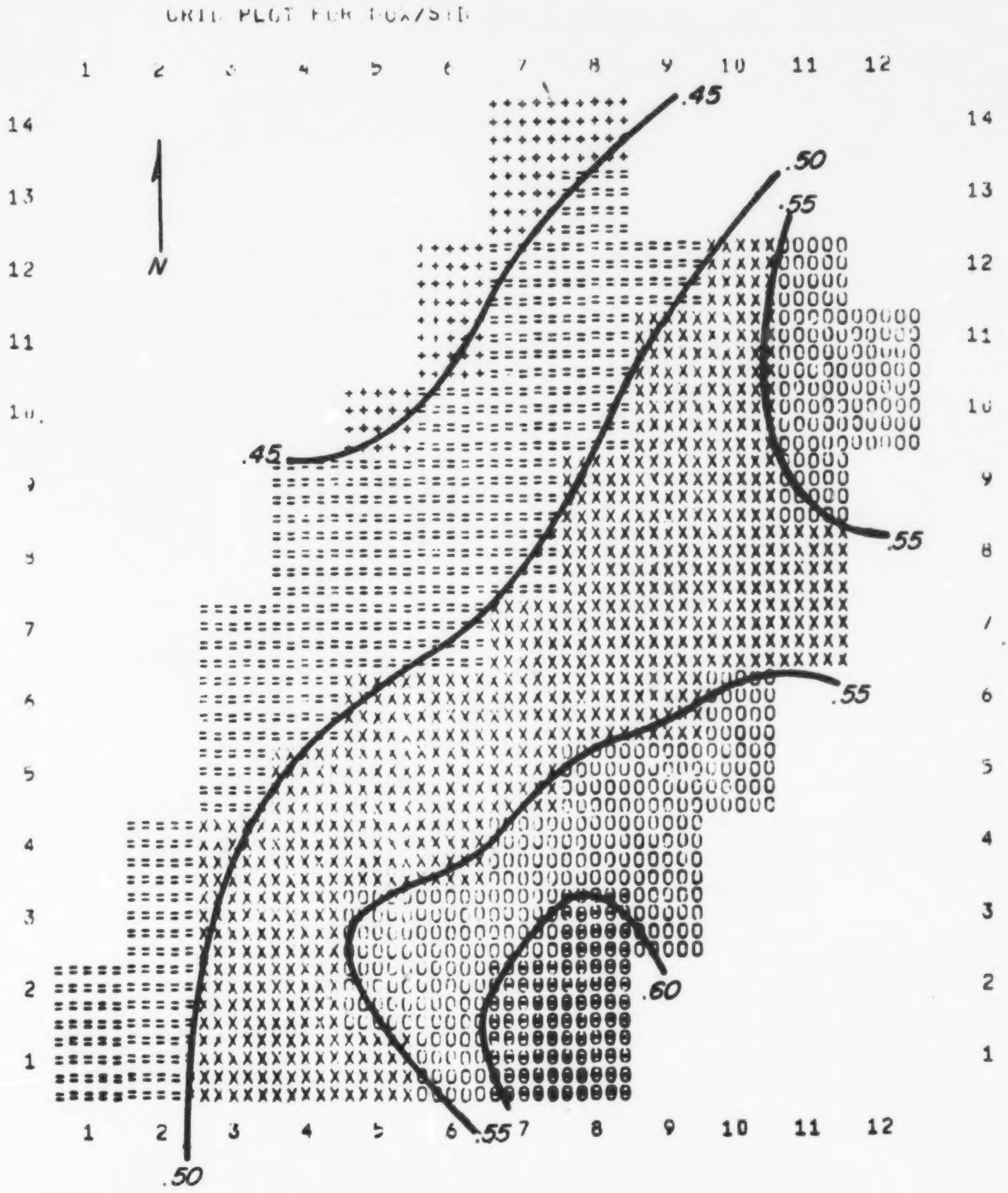
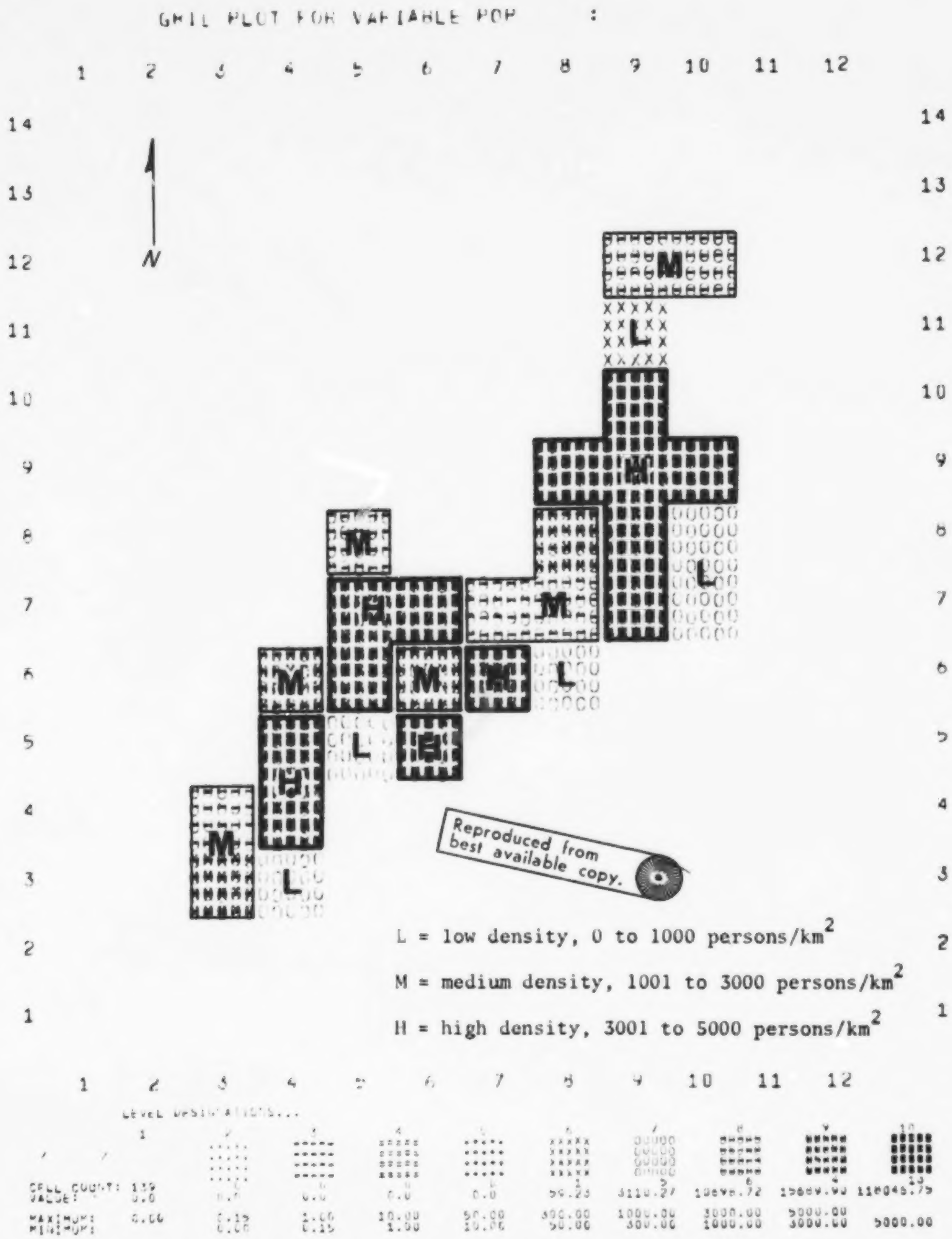

GRID PLOT FOR NOX/STD
N
.45
.45
.50
.50
.55
.55
.55
.55
.60
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1

Figure 32 Air Quality Contours for Nitrogen Oxides for Plan 1C, Expressed as the Ratio of Air Quality/Air Quality Standard


GRID PLOT FOR VARIABLE POP :
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
N
M
L
M
L
M
M
H
M
M
M
L
H
L
H
M
L
LEVEL DESIGNATIONS...
1 2 3 4 5 6 7 8 9 10
CELL COUNT: 139 0 0 0 0 1 5 6 4 13
VALUE: 0.0 0.0 0.0 0.0 0.0 59.23 3110.27 10898.72 15689.90 118045.75
MAXIMUM: 0.00 0.10 1.00 10.00 50.00 300.00 1000.00 3000.00 5000.00 5000.00
MINIMUM: 0.00 0.10 1.00 10.00 50.00 300.00 1000.00 3000.00

L = low density, 0 to 1000 persons/km^2

M = medium density, 1001 to 3000 persons/km^2

H = high density, 3001 to 5000 persons/km^2

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Figure 33 Grid Plot for Population Density for Plan 1

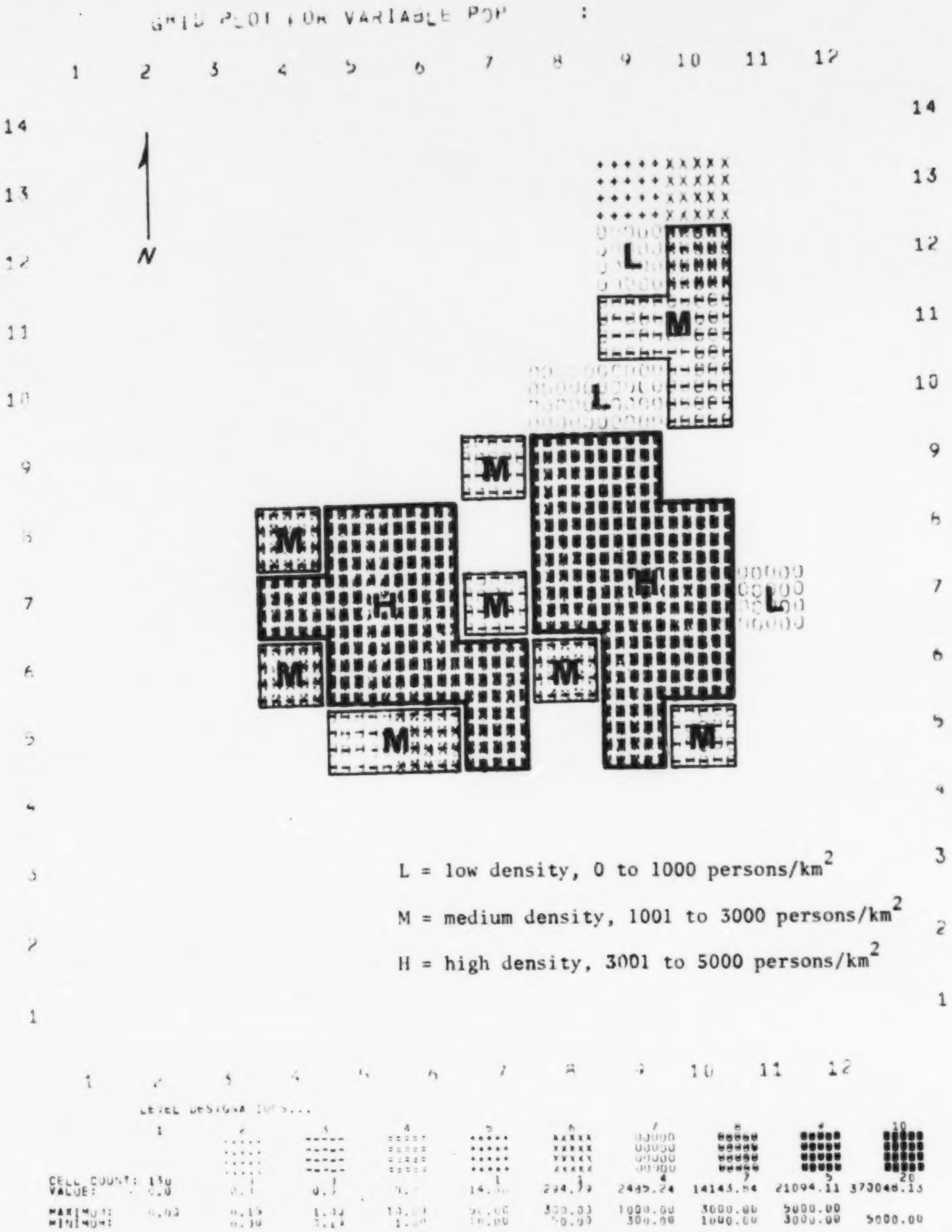
GRID PLOT FOR VARIABLE POP
N
L
M
H
L = low density, 0 to 1000 persons/km²
M = medium density, 1001 to 3000 persons/km²
H = high density, 3001 to 5000 persons/km²
LEVEL DESIGNATIONS...
CELL COUNT:
VALUE:
MAXIMUM:
MINIMUM:
2445.24
14143.54
21094.11
370048.15
1000.00
300.00
3000.00
1000.00
5000.00
3000.00
5000.00

Figure 34 Grid Plot for Population Density for Plan 1A

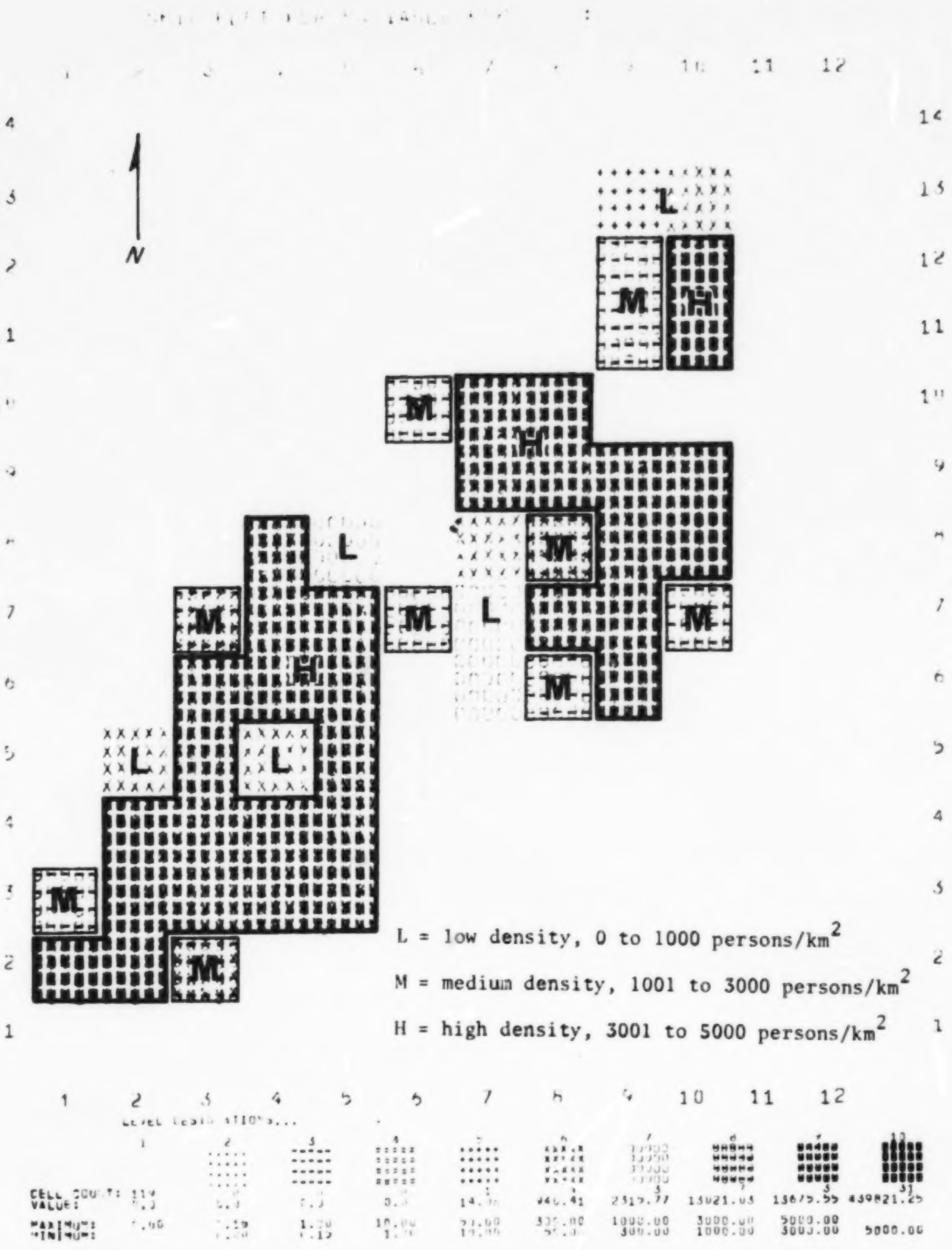
N
L = low density, 0 to 1000 persons/km^2
M = medium density, 1001 to 3000 persons/km^2
H = high density, 3001 to 5000 persons/km^2
L
M
H
1
2
3
4
5
6
7
8
9
10
11
12
13
14
LEVEL DESIGNATIONS...
CELL COUNT:
VALUE:
MAXIMUM:
MINIMUM:

Figure 35 Grid Plot for Population Density for Plan 1B

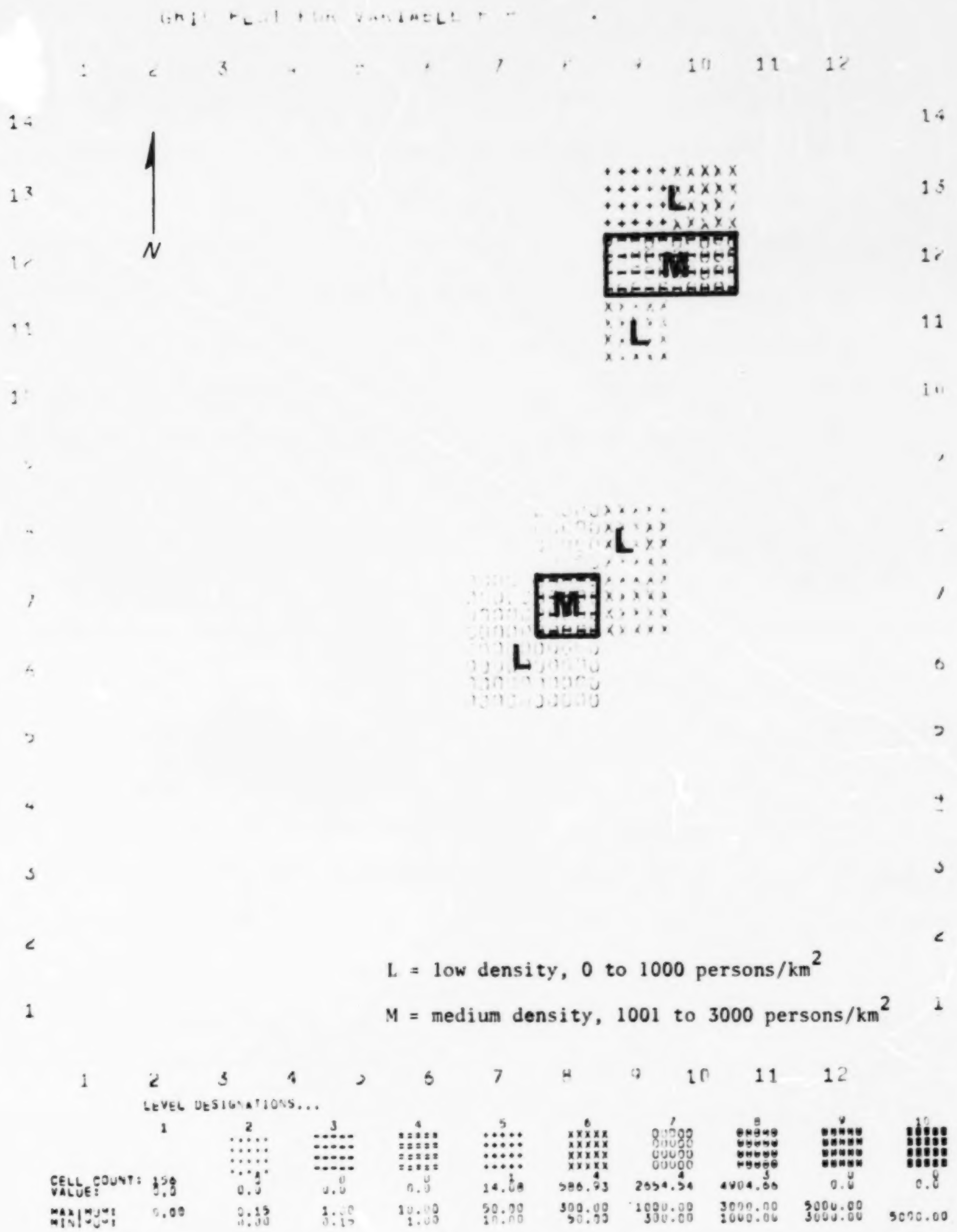
GRID PLOT FOR VARIABLE
N
L
M
L = low density, 0 to 1000 persons/km²
M = medium density, 1001 to 3000 persons/km²
1 2 3 4 5 6 7 8 9 10 11 12
14 13 12 11 10 9 8 7 6 5 4 3 2 1
LEVEL DESIGNATIONS...
1 2 3 4 5 6 7 8 9 10
CELL COUNT: 156 0 0 0 1 4 4 3 0 0
VALUE: 0.0 0.0 0.0 0.0 14.08 586.93 2654.54 4904.66 0.0 0.0
MAXIMUM: 0.00 0.15 1.00 10.00 50.00 300.00 1000.00 3000.00 5000.00
MINIMUM: 0.00 0.15 1.00 10.00 50.00 300.00 1000.00 3000.00 5000.00

Figure 36 Grid Plot for Population Density for Plan 1C

3.2.3 Results of Plan Ranking

In order to rank the four alternative land use plans on the basis of the combined effects of all pollutants, the Normalized Impact Parameter Ranking Index (defined in Section 2.2.3) was calculated for a variety of choices of impact parameters and receptors of interest. Impact parameters based on average receptor exposures were considered to be the most meaningful representation of concerns and objectives in the planning process. The use of impact parameters based on integrated receptor exposures does provide useful information, but the results of the ranking based on such integrated impacts are not as meaningful to planners who must also respond to other planning considerations and constraints. The logical result of evaluating plans on the basis of integrated impact measures would be the selection of a plan consisting predominantly of those land use categories most tolerant to air quality, a result which may be in direct conflict to the needs of the planner to provide housing and employment, to fulfill transportation demands, and to achieve balanced land uses.

Examination of Table 10 shows that the resultant ranking of plans based on the Normalized Impact Parameter Ranking Index for average receptor exposures is (from best to worst) Plans 1, 1B, 1A, and 1C. This ranking occurs for nearly all receptors of interest and is consistent with intuitive judgment based upon the visual examination of air quality contours. Moreover this multipollutant ranking order is the same as the ranking of plans based on single pollutants for most receptors of interest.

TABLE 10

RELATIVE RANKING OF PLANS ON BASIS OF QUANTITATIVE RANKING INDEX FOR COMBINED POLLUTANT IMPACTS

PLAN RANK (Best to worst)	AVERAGE AREA EXPOSURE		AVERAGE POPULATION EXPOSURE		AVERAGE STUDENT EXPOSURE		AVERAGE RESIDENTIAL EXPOSURE		AVERAGE OPEN SPACE		AVERAGE COMMERCIAL AND INDUSTRIAL AREA EXPOSURE	
	Plan	Index(1)	Plan	Index	Plan	Index	Plan	Index	Plan	Index	Plan	Index
1	1	0.97	1	0.95	1	0.96	1	0.96	1	0.96	1	0.96
2	1B	1.00	1B	0.97	1B	1.00	1B	0.97	1B	0.99	1A	0.99
3	1A	1.004	1A	1.03	1A	1.05	1A	1.02	1A	1.01	1B	1.02
4	1C	1.03	1C	1.04	-(2)	-	1C	1.05	1C	1.07	1C	1.03

PLAN RANK (Best to worst)	INTEGRATED AREA EXPOSURE		INTEGRATED POPULATION EXPOSURE		INTEGRATED STUDENT EXPOSURE		INTEGRATED RESIDENTIAL EXPOSURE		INTEGRATED OPEN SPACE		INDUSTRIAL COMMERCIAL AND INDUSTRIAL AREA EXPOSURE	
	Plan	Index(1)	Plan	Index	Plan	Index	Plan	Index	Plan	Index	Plan	Index
1	1	0.968	1C	0.0332	1	0.49	1C	0.11	1C	0.48	1C	0.52
2	1B	0.996	1	0.540	1A	1.24	1	0.54	1B	0.93	1A	1.07
3	1A	1.002	1A	1.624	1B	2.27	1A	1.51	1A	0.95	1B	1.18
4	1C	1.028	1B	1.798	-(2)	-	1B	1.84	1	1.63	1	1.22

(1) Index = Normalized Impact Parameter Index (as defined in text).

(2) Plan 1C excluded - it has no students.

3.3 Summary of Results of Rapid Plan Evaluation and Ranking Estimation Procedures

The estimation procedures for rapid plan evaluation and ranking as described in Section 2.4 were applied to the four alternative land use plans for the Hackensack Meadowlands to demonstrate the procedures and to compare the resultant rankings with those obtained by use of the AQUIP System.

The emissions for each land use activity were calculated by applying the emission rates listed in Table 4 to the land use acreages and activity levels listed in Table 5. The resultant emissions are tabulated for each plan in Tables 11 to 14. The ranking of the plans in terms of total emissions for each pollutant is summarized in Table 15.

The results show that the ranking order of the plans in terms of total plan emissions is identical for TSP, SO_2, and NO_X. Moreover, this ranking order (namely, Plans 1, 1A, 1B and 1C, from best to worst, respectively) follows the order of increasing amounts of area devoted to manufacturing land use, as indicated in Table 5. The ranking order of plans in terms of CO emissions (namely, Plans 1C, 1, 1A, and 1B, respectively) is shown to follow the order of increasing vehicle trip miles (VTM) for each plan. The ranking order of plans in terms of HC emissions (namely, Plans 1, 1C, 1A, and 1B, respectively) is dominated by the combination of two factors: manufacturing and vehicle trip miles. The data in Tables 11 to 14 indicate that the ranking order based on HC emissions would be the same as for TSP, SO_2 and NO_X were it not for the low VMT in Plan 1C.

This procedure for the rapid estimation of the relative ranking of plans based on total pollutant emissions is somewhat similar to the procedure for the ranking of plans based on the calculation of the "integrated total

TABLE 11

Total Emissions For Plan 1 Using Rapid Estimating Techniques

Land Use Categories	Pollutant Emissions (Tons/Yr)				
	TSP	SO_2	CO	HC	NO_x
Residential					
10 Dwelling units/acre	2.5	0.1	3.4	1.2	0.7
20 "	-	-	-	-	-
30 "	-	-	-	-	-
50 "	122.5	78.4	2.4	36.7	58.8
80 "	-	-	-	-	-
Subtotal	124.0	78.5	5.8	37.9	59.5
Commercial & Industrial					
Commercial	23.5	17.6	0.4	4.7	37.2
Manufacturing (lt & heavy) (1)	2548.0	2548.0	27.4	407.7	2450.0
Research	1.6	11.8	0.8	3.9	27.4
Distribution	129.4	97.0	2.2	25.9	204.8
Special Use (2)	5.9	4.4	.1	1.2	9.3
Airport	35.0	350.0	1050.0	122.5	35.0
Transportation Center	25.2	18.2	.3	5.0	42.0
Subtotal	2651.6	3047.0	1081.2	507.9	2805.7
Open Space					
Water	0	0	0	0	0
Parks & Conservation Land	0	0	0	0	0
Subtotal	0	0	0	0	0
Other					
Highways & Railroads	364.0	208.0	5720.0	520.0	780.0
Parking Lots	8.0	8.0	24.0	6.0	2.0
Subtotal	372.0	216.0	5744.0	526.0	782.0
TOTAL EMISSIONS (Tons/Yr)	3150	3340	6830	1070	3650

(1) Assumes 50% light & 50% heavy

(2) Includes Cultural Center

Table 12

Total Emissions For Plan 1A Using Rapid Estimating Techniques

Land Use Categories	Pollutant Emissions (Tons/Yr)				
	TSP	SO_2	CO	HC	NO_x
Residential					
10 Dwelling units/acre	4.9	0.2	6.9	2.3	1.4
20 "	123.5	82.3	2.7	37.0	58.3
30 "	-	-	-	-	-
50 "	-	-	-	-	-
80 "	156.8	109.8	3.9	49.4	78.4
Subtotal	285.2	192.3	13.5	88.7	138.1
Commercial & Industrial					
Commercial	23.5	17.6	0.4	4.7	37.2
Manufacturing (lt & heavy)(1)	4459.0	4459.0	48.0	713.4	4287.5
Research	-	-	-	-	-
Distribution (2)	111.7	83.8	1.9	22.4	176.9
Special Use	-	-	-	-	-
Airport	35.0	350.0	1050.0	122.5	35.0
Transportation Center	7.6	5.5	0.1	1.5	12.6
Subtotal	4636.8	4915.9	1100.4	864.5	4549.2
Open Space					
Water	0	0	0	0	0
Parks & Conservation Land	0	0	0	0	0
Subtotal	0	0	0	0	0
Other					
Highways & Railroads	491.7	281.0	7727.5	702.5	1053.7
Parking Lots	8.0	8.0	24.0	6.0	2.0
Subtotal	499.7	289.0	7751.5	708.5	1055.7
TOTAL EMISSIONS (Tons/Yr)	5420	5400	8865	1660	5745

(1) Assumes 50% light & 50% heavy

(2) Includes Cultural Center

TABLE 13

Total Emissions For Plan 1B Using Rapid Estimating Technique

Land Use Categories	Pollutant Emissions (Tons/Yr)				
	TSP	SO_2	CO	HC	NO_x
Residential					
10 Dwelling units/acre	2.5	0.1	3.4	1.2	0.7
20 "	-	-	-	-	-
30 "	88.2	58.8	1.9	26.5	41.6
50 "	-	-	-	-	-
80 "	294.0	205.8	5.9	92.6	147.0
Subtotal	384.7	264.7	11.2	120.3	189.3
Commercial & Industrial					
Commercial	17.6	13.2	.3	3.5	27.9
Manufacturing (lt & heavy) (1)	4777.5	4777.5	51.4	764.4	4593.7
Research	-	-	-	-	-
Distribution	129.4	97.0	2.2	25.9	204.8
Special Use (2)	-	-	-	-	-
Airport	35.0	350.0	1050.0	122.5	35.0
Transportation Center	7.6	5.5	0.1	1.5	12.6
Subtotal	4967.1	5243.2	1104.0	917.8	4874.0
Open Space					
Water	0	0	0	0	0
Parks & Conservation Land	0	0	0	0	0
Subtotal	0	0	0	0	0
Other					
Highways & Railroads	530.2	303.0	8332.5	757.5	1136.3
Parking Lots	8.0	8.0	24.0	6.0	2.0
Subtotal	538.2	311.0	8356.5	763.5	1138.3
TOTAL EMISSIONS (Tons/Yr)	5890	5820	9470	1800	6200

(1) Assumes 50% light & 50% heavy

(2) Includes Cultural Center

TABLE 14

Total Emissions For Plan 1C Using Rapid Estimating Technique

Land Use Categories	Pollutant Emissions (Tons/Yr)				
	TSP	SO_2	CO	HC	NO_x
Residential					
10 Dwelling units/acre	2.5	0.1	3.4	1.2	0.7
20 "	-	-	-	-	-
30 "	-	-	-	-	-
50 "	-	-	-	-	-
80 "	-	-	-	-	-
Subtotal	2.5	0.1	3.4	1.2	0.7
Commercial & Industrial					
Commercial	5.9	4.4	0.1	1.2	9.3
Manufacturing (lt & heavy) (1)	5733.0	5733.0	61.7	917.3	5512.5
Research	-	-	-	-	-
Distribution (2)	294.0	220.5	4.9	58.8	465.5
Special Use	-	-	-	-	-
Airport	35.0	350.0	1050.0	122.5	35.0
Transportation Center	7.6	5.5	0.1	1.5	12.6
Subtotal	6075.5	6313.4	1116.8	1101.3	6034.9
Open Space					
Water	0	0	0	0	0
Parks & Conservation Land	0	0	0	0	0
Subtotal	0	0	0	0	0
Other					
Highways & Railroads	339.5	194.0	5335.0	485.0	727.5
Parking Lots	8.0	8.0	24.0	6.0	2.0
Subtotal	347.5	202.0	5359.0	491.0	729.5
TOTAL EMISSIONS (Tons/Yr)	6425	6515	6480	1595	6765

(1) Assumes 50% light & 50% heavy

(2) Includes Cultural Center

TABLE 15

Results of Rapid Plan Ranking Procedures

Ranking Based on Total Pollutant Emissions (Plans Only)					
Rank (Best to Worst(1))	TSP	SO_2	CO	HC	NO_x
1	1	1	1C	1	1
2	1A	1A	1	1C	1A
3	1B	1B	1A	1A	1B
4	1C	1C	1B	1B	1C

(1) Least total emissions to greatest total emissions

Ranking Based on Total Pollutant Concentrations(2) (Plans plus Background)					
Rank (Best to Worst)	TSP	SO_2	CO	HC	NO_x
1	1	1	1C	1	1
2	1B	1B	1	1A	1B
3	1A	1A	1A	1C	1A
4	1C	1C	1B	1B	1C

(2) Ranking is based on "integrated total area exposure" impact parameter and is taken from Table 9.

area exposure" impact parameter as described in Section 2.2.2. The results of this quantitative ranking based on total pollutant concentrations over the planning region (listed in Table 9) are also summarized in Table 15 and provide a basis for assessing the accuracy of the rapid estimation ranking methodology.

Comparison of the ranking order resulting from the two methodologies shows that the rapid estimation technique gives a correct ordering of plans in terms of CO. For TSP, SO_2 and NO_X, however, the emissions method yields a slightly different ranking order (although the relative ranking of plans is the same for all three pollutants regardless of the ranking of methodology). Specifically, Table 15 indicates that the ranking in terms of pollutant emissions implies Plan 1A is better than Plan 1B, while ranking in terms of pollutant concentrations implies just the opposite. As observed from Table 5 Plans 1A and 1B have similar percent mix of land use categories but differ in the spatial distribution of these land uses within the planning region. As a consequence, it is demonstrated that the effect of the more widely dispersed manufacturing land use activities within Plan 1B results in lower pollutant concentrations, even though total emissions are greater than in Plan 1A. Finally, it is noted that no reasonable comparisons can be made between results of the two ranking methods in the case of HC. As noted in Table 8 the background HC pollutant concentrations represent approximately 99% of the total concentrations within the planning region, clearly dominating the ranking based on total concentrations regardless of the relative levels of emissions resulting from the different plans.

Despite the difficulties of comparing the results of ranking based on total plan emissions with results of ranking based on total (i.e., plan plus background) pollutant concentrations, the rapid estimation ranking technique indicates clearly that Plan 1 has the least net impact on regional air quality for four of the pollutants and that Plan 1C has the greatest impact on regional air quality for three of the pollutants (in agreement with the results of the detailed AQUIP System analysis).

The false indication of the ranking of Plans 1A and 1B for TSP, SO_2 and NO_X illustrates clearly the basic necessity for examining pollutant concentrations, especially in cases where the essential differences among plans are in the spatial location of land uses. The analysis of emissions cannot account for differences in air quality due to spatial (or temporal) distributions of land uses and activities, and cannot account for the influence of meteorology on pollutant concentrations.

The false indication of the ranking of plans in terms of HC emissions illustrates a second basic necessity for examining pollutant concentrations. The apparent closeness in agreement between the two methods is mostly coincidence; the ranking based on total air quality concentrations is due to the influence of background air quality - variations in the contributions from the plans, no matter how large, have essentially no impact on the ranking. Thus in regions near urban centers, or where it is known that background concentrations will be high, total emissions from plans cannot be relied upon to indicate levels (or the ranking) of total air quality for the planning region. Conversely, in areas of low background concentrations, the total emissions from plans can be a reasonable indicator of the ranking of plans (although not as suitable as pollutant concentrations).

4. CONCLUSIONS AND GUIDELINES FOR PLANNERS

4.1 Introduction

One of the basic objectives of the study of air pollution for the Hackensack Meadowlands land use plans was to derive a set of guidelines which could be applied to the land use and transportation planning process in general for the consideration of air pollution. The purpose of this section is to provide a summary of the basic conclusions from the study in the form of suggested planning guidelines.

These guidelines are expressed quantitatively to the greatest extent possible. Quantitative results, however, are necessarily based on the specific plan characteristics and assumptions for the Meadowlands and therefore tend to be less generally applicable to other plans and planning situations. Consequently, many of the guidelines are given in the form of qualitative statements of general results.

In summary these planning guidelines are based on the results of an air pollution study characterized by:

1. The analysis of four comprehensive land use plans for the Hackensack Meadowlands in the 1990 time frame.
2. The analysis of regional scale air quality (that is, air quality for a region covering approximately 100 km^2).
3. The analysis of the impact of regional air quality on specific land use categories and receptors.
4. The analysis of annual and seasonal average concentrations for five pollutants: particulates, sulfur dioxide, carbon monoxide, hydrocarbons, and nitrogen oxides.

5. The analysis of pollutant concentrations resulting both from the plan itself and "background" sources (that is, sources outside the planning region which significantly affect concentration levels within the planning region).

By contrast, these guidelines are not applicable to air quality problems of a localized or microscale nature such as those associated with the design and arrangement of buildings and other facilities. Likewise, these guidelines are not based on the analysis of relationships between air pollution considerations and other environmental concerns, nor upon relationships between pollutant concentration levels and direct impacts such as health effects or costs.

In the following sections,planning guidelines are presented in terms of three important relationships between land use plans and air pollution. The first is background air quality which must be of paramount concern in plan design because it represents a basic set of constraining factors to the planner, especially in urban regions. The second is the effect of the primary factors associated with the land use plan itself which influence regional air quality concentrations and spatial patterns: (1) the mix of land use categories: (2) the location of land use categories within the planning region; and (3) the intensity of land use activities. These items represent the primary plan design factors which can be adjusted by the planner to modify regional air quality levels. Third are the climatological and topographical characteristics of a region, which should play an important part in the consideration of air pollution by the planner.

A final section indicates some precautions on the use of these suggested planning guidelines, and discusses the basic limitations on the applicability and generality of the guidelines.

4.2 Effect of Background Sources on Air Quality

4.2.1 Regions with High Background Pollutant Concentration Levels

The results of the Meadowlands air pollution study show that if the background levels of pollution are high within the planning region, then the direct contribution from the plan may be only a small percent of the total air quality. As a result, land use planning may not be an effective means of reducing regional air pollution levels. However, since the actual concentrations resulting from the plan itself may be large, selection of a land use plan to minimize regional air pollution levels is critically important.

Background concentration levels can be defined as being high either by comparison to concentrations resulting directly from a plan, or by comparison to air quality standards. It is suggested that the appropriate standards be used since they represent an absolute basis for comparison. For reference, the annual average background concentrations for the Meadowlands area are listed in Table 16 for the years 1970 and 1990. The values for 1970 are averages based on measurements data from state monitoring stations in the vicinity of the Meadowlands, and the values for 1990 are projected averages based on the Meadowlands study. For planning purposes, these results can be considered to be representative of general background levels in highly industrialized major metropolitan regions.

TABLE 16

ESTIMATED BACKGROUND AIR QUALITY LEVELS IN THE NEW JERSEY HACKENSACK MEADOWLANDS

Pollutant	1970(1)	1990(2)	Air Quality Standards(3)
Particulates ($\mu g/m^3$)	113.3	120	70.1
SO_2 (ppm)	0.043	0.008	0.02
CO (ppm)	4.24	0.71	1.25
HC (ppm)	2.09	2.46	0.24
NO_x (ppm)	0.113	0.024	0.05

(1) 1970 average annual concentrations, based on New Jersey Department of Environmental Protection measurements at Bayonne, Jersey City, Newark, Paterson, and Hackensack (HC and NO_x at Newark and Bayonne only).

(2) 1990 annual average background concentrations, estimated from data in Tables 7 and 8, and verified by examination of SYMAP graphic displays of 1990 background air quality (Figures B-1 to B-5, Appendix B, Task 3 Report).

(3) Annual standards or extrapolated equivalent (see Table 7).

If the spatial variations in background concentration patterns are significant (as was the case in the Meadowlands study) then it is essential to locate land use activities relative to such concentration patterns:

1. To meet ambient air quality standards.
2. To reduce the net regional pollutant concentrations.
3. To reduce the net impact of regional air pollution on critical receptors, such as elementary schools, parks, playgrounds nursing homes, and hospitals.

As an example, the background air quality contours for all pollutants observed in the Hackensack Meadowlands show generally a north-south orientation with concentrations increasing with a strong gradient from west to east. This annual average gradient results from the influence of the New York City urban core region, which is "upwind" of the Meadowlands during those times for which winds occur from the east. As a consequence, it would appear worthwhile to consider locating sensitive receptors such as residential areas or special population groups in the western portion of the Meadowlands where background concentrations are generally lowest. This would require an analysis of the tradeoff between the advantages of reducing the air pollution impact on population vs. the disadvantages associated with increasing pollution levels as a result of increased vehicle trip miles resulting from longer commuting distances between the outer region and the core area employment centers.

4.2.2 Regions with Low Background Pollutant Concentration Levels

Low background pollutant concentrations within a planning region can occur in two ways. First, the planning region may be located within a nonurbanized or non-industrialized area; and secondly, the planning region itself may encompass an area within the urban region large enough that the relative influence of background concentrations is low. The result, in either case, is that the percent variation among alternative land use plans may be relatively large. For example, results from the Meadowlands air pollution study show that in the absence of background concentrations, variations in plan design characteristics can result in concentration levels which vary by as much as a factor of two between plans. Clearly, under such circumstances, land use planning can be extremely effective in reducing regional pollutant concentration levels. From an alternative viewpoint, in regions having low background levels the planner has a greater degree of freedom in plan design to consider factors other than air pollution since air quality within the region can tolerate larger pollutant levels from the plan without exceeding standards. Therefore, air pollution should be an important consideration in the land use planning process for regions having low background concentration levels.

On the other hand, if the percent variation among plans is low, then land use planning may not be particularly effective as a means for the abatement of pollution on a regional scale. The results from the Meadowlands study indicate that variations in total pollutant concentrations among plans which are on the order of 15% or less, represent a threshold below which land use planning is relatively ineffective for reducing regional air pollution levels. Even under such circumstances, however, air pollution should be considered by the planner in order to assess the impact on specific critical receptors, and ultimately in order to assess localized or microscale pollution impacts.

4.2.3 Conclusions Concerning Background Air Quality

As a consequence of these observations based on the Meadowlands study it is concluded that:

1. If total air pollutant concentration levels do not exceed ambient air quality standards and if variation in impact from alternative plans on total air quality is under 15%, then the planner can be neutral in his choice of a plan with respect to regional air quality considerations. That is, if necessary, he can give greater weight to planning considerations other than air pollution in the selection of land use plans.
2. If background air pollutant concentration levels represent greater than 60 to 70% of the total air quality levels, then land use planning is not an effective means for the abatement of regional air pollution problems.
3. The extent of the planning region therefore should be chosen such that the background concentration levels represent less than 30 to 40% of the total air quality levels in order to assure that land use planning will be an effective means for the abatement of regional air pollution problems.
4. The planner cannot be neutral with regard to consideration of microscale impact of any plan without analysis of air quality at that level of detail; results of regional-scale analyses are not adequate to identify the existence of, nor to assess the severity of microscale (i.e., localized) air pollution problems.

4.3 Effect of Plan Design Factors on Air Quality

Based on the results of the Hackensack Meadowlands air pollution study, it is concluded that the plan design factors which have primary influence on regional air pollutant concentrations and spatial patterns are the mix, location, and intensity of land use activities. The relationship of these plan design factors to regional air quality is discussed below.

4.3.1 Mix of Land Uses

The Meadowlands study shows that the land use category designated as "Manufacturing" has a dominant influence on particulates, SO_2, and NO_X concentration levels and patterns. In fact, the emissions from this land use category are shown to be a factor of from 10 to 1000 times greater than those from all other land use categories if examined on a basis of emissions per unit of land area. The study also shows that motor vehicular traffic is a dominant influence on CO concentration levels and patterns. Over 90% of the CO emissions result from motor vehicle traffic, airport operations, and other transportation-related land use activities (for example, parking lots and transportation centers).

Consequently, on the basis of the relative emission rates per unit land area, the Meadowlands study shows that regional air quality is highly sensitive to manufacturing and transportation-related land use categories and is relatively insensitive to nearly all other land use categories. To illustrate the effect, if the emissions per acre for manufacturing are 100 times those of a residential area, then 1% of the total area devoted to manufacturing will have the same net emissions as would be generated by devoting the entire land area to residential use. These relative sensitivity factors are listed in Table 4, which shows the annual emissions per unit land area (or per unit activity where appropriate, such as emissions per VMT for motor vehicular traffic, or emissions per hour of idling for parking lot situations) for each of the different land use categories. It is to be noted also that these sensitivities differ by pollutant as well as by land use category.

The use of this table is illustrated by the following example which examines the relative sensitivity of regional air quality to the mix of open space vs. manufacturing land use categories. From Table 5 a comparison of the percent mix of land uses for the various plans shows that Plan 1 has 8% manufacturing and 8% research. It also has 31% open space and 6% residential area, for a total of 37% for these two categories. Plan 1A, on the other hand, has 14% manufacturing and no research. This plan has 18% open space and 17% residential area, a combined total of 35%. Finally, Plan 1B has 15% manufacturing and no research. It has 18% open space and 21% residential area for a combined total of 39%. Thus if the 8% research category in Plan 1 were converted to an additional 8% manufacturing land use (for a total of 16% land use devoted to manufacturing in Plan 1) then, as indicated in Table 5, Plans 1, 1A, and 1B would be very similar in the percent mix of land uses except for the relative mix between open space and residential area.

From the data in Tables 4 and 5 the total emissions of SO_2 resulting directly from sources within Plan 1 can be calculated before and after the conversion of the 8% research land use category; the result is an estimated 73% increase in emissions. If it is further assumed that these additional emissions (which arise from 8% of the Meadowlands area) diffuse uniformly over the entire Meadowlands region, then average regional SO_2 concentrations generated by the plan itself will increase by 5.8%.

The data in Table 8 shows that background SO_2 concentrations for Plan 1 range between 35% and 55% of total regional SO_2 concentration levels. If it is arbitrarily assumed that the average background level is 45% of total air quality, then the net increase in average regional air quality within the Meadowlands planning region would be (1.0 - 0.45)5.8% or a total of 3.2%. Comparison of the relative ratios of average regional SO_2 concentrations for Plans 1, 1A, and 1B as listed in Table 9 shows average concentrations for Plan 1A to be 5.9% higher than for (the original) Plan 1, and average concentrations for Plan 1B to be 3.2% higher than for (the original) Plan 1. Since the conversion of 8% of the total land area from the research category to manufacturing within Plan 1 would cause an approximate increase in total regional SO_2 concentrations in Plan 1 of 3.2%, the resultant air quality for Plan 1 thus would be within the same range of values as regional SO_2 concentrations for Plans 1A and 1B, even though Plan 1 still retains 31% open space and only 6% residential area.

It can be concluded from this simple example that open space is not a dominant influence on regional air quality concentration levels. Rather, regional air quality is far more sensitive to land use categories having large emission rates. A direct trade between manufacturing and open space land use, for example, would be highly beneficial to regional air quality levels, not because of the addition of open space within the land use plan, but rather because of the deletion of manufacturing. The primary benefits of open space would appear to be associated with microscale effects rather than regional scale effects.

4.3.2 Location of Land Uses

The location of land use categories is a major factor both in determining patterns of regional air pollutant concentrations, and in determining the degree to which critical receptors within the plan are exposed to pollutant concentrations. The relative location of a given mix of land use categories within a plan will determine the concentration patterns resulting from the plan without greatly influencing average regional concentration levels. If background concentrations are high relative to those resulting from the plan alone, then the location of land uses will have only a small influence on regional air pollutant concentration patterns. However, since receptors and critical land use activities are always exposed to total air quality levels (i.e., plan plus background contributions), the location of land uses within the plan will have a major influence on receptor impacts, especially if background concentration levels are high and have a significant degree of spatial variation.

In the case of plans having similar mixes of land use activities, land uses should be located within the plan on the basis of the following considerations:

1. Air pollutant concentrations must comply with appropriate standards at all locations.
2. Planners should attempt to minimize air pollution concentrations in areas where population density will be high in order to minimize exposure of population and other critical receptors.
3. Planners should favor maximum reduction of concentrations at all locations.

Primary attention should be devoted to the location of the dominant land use emission sources within the planning region relative to background concentration levels and patterns (especially where large variations in background levels and patterns occur within the planning region) to assure compliance with appropriate standards. Dispersal of large individual emission sources (e.g., power plants or incinerators) may eliminate localized problems or "hot spots", but will not especially reduce average ground level concentrations throughout a region. Land use categories that are not highly sensitive to the effects of air pollution should be located in regions of higher background concentration levels in preference to those land use categories which are more sensitive to the effects of air pollution. In general, the latter should be located in regions of lower background concentrations to the greatest extent possible.

As was demonstrated in the Meadowlands study, land uses other than those few having very high emission rates can be located rather arbitrarily within the planning region without significantly affecting the air pollutant concentration levels and patterns on a regional scale. Moreover, it is also evident from Table 4 that critical receptors are generally associated with land use categories which have relatively low emission rates. (There are exceptions, of course, especially if microscale effects are considered; for example, hospitals or large schools may generate power on site, and the residential clusters in Plan 1 were large enough to be considered as point sources.) Thus, in general, the planner can locate critical receptors within the plan without causing any significant impact on regional air quality levels in order to reduce the air pollution impact on these critical receptors and land use activities.

This principle was illustrated in the Meadowlands study where the impact of total air pollutant concentration levels on population was observed to be far less in Plan 1B than in Plan 1A even though both plans have essentially the same mix of land use categories (in fact, Plan 1B has a slightly higher total population). This resulted directly from locating most of the population in Plan 1B in the western portion of the planning region where background concentrations are lowest.

In following these guidelines, however, it is to be cautioned that land use activities are in fact interrelated and cannot be located independently nor without the consideration of emissions associated with such related activities. For example, although residential areas generally produce very low emissions from activities such as home spacing heating, a far more important consideration in terms of location as a pollution-related plan design factor is the relationship between residential areas and other land use activities. In particular, one of the more important considerations in terms of air pollution is that of satisfying the demand for transportation. The population must have access to centers of employment, recreation, social activities, shopping centers, and so forth. Most of this transportation demand is currently satisfied within urban metropolitan regions by means of the personal automobile. Consequently, unless life styles and living patterns are radically changed within the 1990 time frame, the placement of residential areas, commercial areas, and other centers of social and occupational activity will generate motor vehicle traffic, which in turn will influence pollution concentrations and patterns for CO and other automobile-related pollutants. Consequently, even though a residential area does not directly have an associated CO emissions rate, nevertheless, the specific location of such a residential area will generate some amount of vehicle traffic and hence CO emissions in the vicinity of the residential area.

Finally, the results of the Meadowlands study show that the location of land use categories, particularly major emission sources within the plan, can also benefit regional air pollutant concentration levels. By dispersing such land use activities throughout the plan (rather than concentrating such activities within a single region) lower regional air pollutant concentration levels can be achieved for planning alternatives having similar mixes of land use activities. In effect, such dispersal of large emission sources results in a larger effective mixing volume for the pollutants, leading to lower average regional concentration levels. This principal is illustrated in the Meadowlands study by the comparison of Plans 1A and 1B. As indicated in Tables 12 and 13, emissions for Plan 1B are on the order of 8% higher than those for Plan 1A for particulates, SO_2, and NO_X (i.e., the pollutants predominantly associated with manufacturing). However, since the land uses devoted to manufacturing are more widely dispersed within Plan 1B than in Plan 1A, the average regional concentration levels for Plan 1B are as much as 2 to 3% lower than for Plan 1A for the three pollutants as is indicated in Table 9.

4.3.3 Intensity of Land Use

The "intensity of land use" as used in the context of this report refers either to the fraction of acres of land use per acre of land area or to the actual density of land use activities such as population density or residential dwelling units per acre. From the results of the Meadowlands study it was observed that intensity of land use represents a third important plan design factor which influences regional air quality patterns.

Intensity is partially related to land use mix as a planning design factor. In particular a lower intensity of a land use category within a given region is the equivalent of a decrease in the percent of that land use category within the region. Intensity is also partially related to the location (dispersal) of land use as a plan design factor. For example, if a plan which has the same percent mix of land uses as another plan, but has a lower intensity of a particular land use category, then that particular category is necessarily more widely dispersed throughout the plan. As a consequence, the major effects on regional air pollution due to each of these factors (mix and location of land use) apply also to land use intensity.

For major emission sources intensity can have a very significant impact on regional air pollutant concentration levels. In particular air pollutant concentrations (in the absence of background) are proportional to the total area of manufacturing land use or the total vehicle trip miles. For other sources the impact of intensity as a plan design factor on average regional air quality levels will be negligible. Again, the data in Table 4 for annual emissions per unit land area for each land use category and pollutant shows directly the sensitivity of regional air quality to levels of land use intensity.

For land use categories such as residential area, differences in intensity will most strongly influence the number of receptors (e.g., population) affected by regional concentration patterns. Consequently, for a regional scale analysis the primary influence of land use intensity will be the impact of regional air pollution levels on specific receptors.

Intensity will also strongly influence the microscale design characteristics of a plan, and thus potentially may have a significant impact on localized air quality. For example, the localized patterns of concentrations will be influenced by the effects which the design and arrangement of buildings, highways, and other facilities have on wind fields and pollutant dispersion mechanisms.

It is concluded that land use intensity is an important consideration as a plan design factor which influences regional air quality levels. In general, intensity of land use will have a minor impact on regional air quality in comparison to the impact of the mix and location of land use categories. It is further concluded that the primary impact of variations in land use intensity will occur in terms of the impact of pollutant levels on specific receptors as a result of limiting the number of receptors effected with the plan or within a specific region of the plan.

4.4. Effects of Topography and Meteorology on Air Quality

Local topography and meteorological conditions have a major influence upon air quality patterns. With careful consideration of these factors the planner can enhance air quality within a region through appropriate plan designs. Suggested guidelines for consideration of these factors by the planner are presented here.

4.4.1 Topography

Table 17 summarizes some of the principal effects of topography upon air quality patterns. The Meadowlands region is relatively flat and homogeneous, and air quality patterns in the region are not significantly influenced by the conditions described in Table 17.

The Hackensack River forms a valley in the north-south direction approximately 4 miles (7 km) wide, with a flat river basin and tidal marsh bounded on the west by a ridge ranging from approximately 50 to 100 feet (15 to 30 meters) in height above the basin and bounded on the east by the Palisades, a ridge which ranges from approximately 100 to 200 feet (30 to 60 meters) in height above the basin.

Because the Meadowlands is relatively flat, the local variation in surface roughness associated with development plans (i.e., buildings, roadway rights-of-way, etc.) will be more important than natural topography in determining microscale features in air quality patterns. Thus, the results of the Meadowlands study are generally applicable to other planning areas which have relatively flat and homogeneous terrain. On the other hand, the results of the present study are not considered to be representative of regions having highly variable or unusual terrain.

TABLE 17

PRINCIPAL EFFECTS OF TOPOGRAPHY UPON AIR QUALITY PATTERNS

Topographic Feature	Effects
1. Elevated regions	a. Increased wind speed (and increased ventilation) over hill tops. b. Occasional impacting of elevated plumes on ground level.
2. Deep valleys	a. Channeling of wind flow along the valley axis, resulting in higher average concentrations in the valley. b. Development of stable, drainage winds during calm, nighttime conditions, resulting in higher concentrations along the valley floor.
3. Undulating regions	a. Increased atmospheric turbulence near the ground level during times of moderate or strong winds. This results in lower pollutant concentrations at locations near sources. b. Accumulation of pollutants in low spots during calm, nighttime conditions (i.e., localized drainage wind conditions).
4. Regions of tree cover	a. Enhanced turbulence near the ground during moderate or strong winds, resulting in lower concentrations for locations near sources. b. In fully covered regions, blockage of elevated plumes, resulting in lower concentrations at ground level.
5. Bodies of water	a. Increased moisture content in the local atmosphere, favoring fog formation at low-lying spots, and affecting the removal rate of SO_2 and other pollutants from the atmosphere. b. For larger bodies of water, formation of local circulation (lake and sea breezes) which can cause ground level fumigation on the landward side of sources, during sunny daytime conditions.

4.4.2 Meteorological Effects

The four basic meteorological effects upon air quality levels were described in Section 2.1.3. These are: (1) advection, related to wind speed and direction; (2) diffusion, related to atmospheric turbulence levels; (3) transformation of pollutants, related to humidity, available sunlight and the presence of other substances; and (4) removal of pollutants, related to pollutant characteristics, precipitation and other factors not yet well understood.

In the Meadowlands planning study the long time average concentration profiles (i.e., seasonal and annual averages) have received most attention. Therefore, the most important meteorological information is contained in the long period climatological records available for the region. (It should be noted, however, that evaluations of "worst case" air quality patterns and of small scale details of the patterns must be based on local, instantaneous meteorological data or assumptions.) For evaluation of seasonal and annual averages, both in the Meadowlands study and in similar analyses, the following review of climatological data is suggested:

1. Stability Wind Rose Data

This information is used for the model input data relative to distributions of wind speed, wind direction and stability categories. For the Meadowlands study, the climatological data from Newark Airport was adopted. These data were judged to be representative of the Meadowlands region because the terrain is relatively unchanged between Newark Airport and the planning region. In other situations, where the terrain is significantly different in the planning region compared to the nearest meteorological observing station, the climatological records must be used with reservation, or must be modified to reflect conditions known to exist in the planning region.

The Newark wind rose data indicate that the predominant wind direction is from the west. However, winds from all directions occur during some fraction of the year. Therefore, the Meadowlands region is downwind from New York City during part of the time, and a significant effect of New York is found in the background concentration patterns. (Specifically, average background concentrations are larger on the eastern side of the Meadowlands region, close to New York.)

2. Local Influences Upon Meteorological Patterns

As mentioned above, the terrain is relatively smooth throughout the region of interest. Therefore, it is not necessary to modify the Newark wind rose data for use in the Meadowlands study.

3. Mixing Depth Climatology

Holzworth[29] has summarized mixing depth information for all of the contiguous United States. Low mixing depths (e.g. daytime depths less than 500 meters) result in elevated concentration levels throughout the planning region, because the normal vertical diffusion of pollutants is inhibited. Most air pollution episodes occur during periods when low mixing depths persist for two or more days. The frequency of such episodes is greatest during the autumn months in the northeastern coastal regions of the United States, including the Meadowlands region. However, such episodes can occur during any time of the year.

Although the principal focus of the Meadowlands study has been the regional scale, some general comments about localized air pollution impact (not derived as part of this study) can be added. Two important cases are: (1) large, isolated sources with tall stacks; and (2) ground level sources, such as highways.

Large volume sources with tall stacks will produce maximum ground level concentrations at distances of from 10 to 40 stack heights downwind. The effective range of significant impact from such a stack depends on stack height, mixing depth, wind speed, and other meteorological conditions, but for general plan estimation purposes the effective radius of influence can be considered to be approximately three times the distance between the source and the point of maximum ground level concentration.

In the case of highways, emissions occur at near-ground level, and maximum concentrations occur in the immediate vicinity of the roadway. Maximum concentrations may occur either within the roadway (especially for wide roadways) or within the first 20 meters from the edge of the roadway. The rate of decrease in concentration levels is large for such sources. Concentrations from roadways commonly are reduced to 10% of maximum concentration levels (in the absence of background), within a distance of 100 to 500 meters from the roadway edge, depending largely on local structures and terrain. Therefore buffer zones (where no other sources occur and where public access is limited) are particularly effective for minimizing impact from such sources.

The consideration of meteorology is critically important in the analysis of air pollution consequences of land use plans. Although generally speaking lower total emissions for a plan will result in lower total concentrations within the planning region, it is important to evaluate and rank plans on the basis of pollutant *concentrations* rather than *emissions* for several reasons:

1. Air quality standards and health effects are related to concentration levels.
2. Meteorological conditions are critical in determining the capacity of a region to assimilate local source emissions (that is, to determine conditions under which planned land use developments will exceed or comply with national ambient air quality standards).
3. Meteorology is critical in determining levels of background pollutant concentration transported into and out of the planning region.

4.5 Limitations of Regional Air Quality Considerations

The suggested planning guidelines listed above are based on the results of the analysis of regional air quality considerations and likewise are to be applied only for planning considerations at the regional scale. Since these guidelines are based on results from the Hackensack Meadowlands air pollution study, which involves very specific plans and planning assumptions, care must be exercised in applying these guidelines to other planning situations; the guidelines are of necessity somewhat application specific. For example, the land use emission rates listed in Table 4 provide convenient guidelines for making gross planning estimates; it would be totally unwarranted, however, to assume that these land use emission rates are sufficiently accurate to form the basis for planning decisions in any planning situation or that they were developed for that purpose. Accuracy of the degree required for decision-making can be obtained only by the detailed analysis and evaluation of plans through use of techniques such as the AQUIP System as outlined in this document. However, it is concluded that these guidelines can be generally applied to other planning situations for estimation purposes provided that certain basic conditions as described within this document are reasonably similar; for example, topography, planning time frames, scale of development, and planning assumptions.

In addition it is important to point out that these conclusions and guidelines (derived from regional scale analytical results) are not necessarily valid in the microscale. For example, in the Meadowlands study, it was found that in terms of annual average concentrations, CO appears to comply with the ambient air quality standards as extrapolated to the annual case. However, these results are valid only for long-term average concentrations and do not give adequate information to assess compliance with short-term ambient air quality standards; for example, one hour and 8 hour standards. Air quality over short time periods and small distances is more likely to be determined by localized influences, such as peak-hour traffic, buildups of concentrations due to the layout of structure of facilities (which might prevent adequate ventilation), or to short term extremes in meteorological conditions. Thus, even though regional air pollutant concentrations and impacts are minor for CO there may be serious localized pollution problems. These problems, however, are largely subject to analysis and solution in terms of design or arrangement of specific localized structures and facilities. The procedures for determining such microscale air quality impacts are somewhat different from the approach used for analysis of regional air quality as presented in this study and are oriented toward a different (although important) aspect of the planning process.

We point out also that even at the regional scale of analysis there exists a need for direct interface between regional land use planners who may be concerned primarily with land development planning, and transportation system planners who may be primarily concerned with roadway and transit system facility design and development. In a comprehensive planning agency this distinction may not be necessary, but these responsibilities for planning are often carried out by separate agencies. For example, since motor vehicles alone account for approximately 50% of NO_X and HC emissions and for approximately 90% of CO emissions, there is a clear need for planning the location and capacity of roadways as well as for considering alternative transportation modes in order to achieve regional reductions in air quality from these sources. This would allow the land use planner greater flexibility in allocating land uses; for example, to create desired employment or tax base, or to protect the environmental qualities of a residential area. Conversely, the land use planner must also interface with the transportation planner to adopt land use plans which minimize regional air quality in order to give the traffic planner maximum flexibility to cope with localized pollution problems while satisfying the demand for transportation.

Finally, it must be cautioned that advice concerning the role of air pollution considerations within the land use planning process is not particularly simple to give nor easy to apply: the planner must accommodate many other issues and concerns; he is confronted with numerous constraints ranging from financial resources to social and political attitudes; information upon which to judge the costs, benefits, and other impacts of alternatives is usually inadequate; and the administrative and legal difficulties of implementing proposed plans can be severe. Furthermore, it is not usually the primary concern of land use planning to assume the burden of abatement of exsisting regional and local air pollution problems; this is more appropriately the function of government air pollution control agencies. Rather, the primary objective of considering air pollution in the land use planning process is to augment existing air pollution control measures through appropriate planning measures in order to prevent conditions from occuring in the long-term which would necessitate severe source emission control regulations. The guidelines presented in this document represent considerations concerning air pollution that are appropriate within the planning process to improve region-wide air quality and to reduce the exposure of the general population (as well as high-risk groups within the general population) to high pollutant concentrations.

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GLOSSARY

Activity, Activity Level - basic land use and transportation planning units of intensity of use - vehicles per day on a highway, acres of residential land use, square feet of industrial plant space.

Activity Index - a numerical conversion factor to transform the level of activity specified for a land use category into demand for fuel for heating purposes.

Air Quality Contour - a contour line in a plane (usually the horizontal or vertical) representing points of equal concentrations for a specified air pollutant.

Air Quality Criteria - factors used in this study that represent a basis for decision-making, for example ambient air quality standards.

Air Quality Prediction - the calculation of current or future air pollutant concentrations at specified receptor points resulting from the action of meteorological conditions on source emissions.

Albedo - the fraction of solar radiation reflected from the ground surface.

Ambient Air - that portion of the atmosphere, external to buildings, to which the general public has access.

Ambient Air Quality - concentration levels in ambient air for a specified pollutant and a specified averaging time period within a given geographic region.

Ambient Air Quality Standard - a level of air quality established by federal or state agencies which is to be achieved and maintained; primary standards are those judged necessary, with an adequate margin of safety, to protect the public health; secondary standards are those judged necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

AQUIP - an acronym for Air Quality for Urban and Industrial Planning, a computer-based tool for incorporating air pollution considerations into the land use and transportation planning process.

Atmospheric Boundary Layer - the lower region of the atmosphere (to altitudes of 1 to 2 km) where meteorological conditions are strongly influenced by the ground surface features.

Atmospheric Dispersion Model - a mathematical procedure for calculating air pollution concentrations that result from a specified array of emission sources and a specified set of meteorological conditions.

Average Receptor Exposure - a measure of the average impact of air quality levels on specific receptors; the measure is based on the integrated receptor exposure divided by the total number of receptors in the study region.

Background Air Quality - levels of pollutant concentrations within a study region which are the result of emissions from all other sources not incorporated in the model for the study region.

Background Emissions - the emissions inventory applicable to the background region; that is, all emission sources not explicitly included in the inventory for the study region.

Climatology - the study of long term weather as represented by statistical records of parameters such as winds, temperature, cloud cover, rainfall, and humidity which determine the characteristic climate of a region; climatology is distinguished from meteorology in that it is primarily concerned with average, not actual, weather conditions.

Concentrations - a measure of the average density of pollutants usually specified in terms of pollutant weight per unit (typically in units of micrograms per cubic meter), or in terms of relative volume of pollutant per unit volume of air (typically in units of parts per million).

Default Parameters - values associated with a parameter for a category of activities (such as heavy manufacturing) assigned to the activity parameter for a subcategory of activities (such as electrical machinery production) when the actual value for the subcategory is not known.

Degree Days - the number of degrees the average temperature is below 65° each day; used to determine demand for fuel for heating purposes.

Effective Stack Height - the height of the plume center-line when it becomes horizontal.

Emission Factor - a numerical conversion factor applied to fuel use and process rates to determine emissions and emission rates.

Emissions - effluents into the atmosphere, usually specified in terms of weight per unit time for a given pollutant from a given source.

Emissions Inventory - a data set describing the location and source strength of air pollution emissions within a geographical region.

Emissions Projection - the quantitative estimate of emissions for a specified source and a specified future time.

Equivalent Ambient Air Quality Standards - air quality levels adopted in this study to permit analysis of all air pollutants in terms of annual averages; in cases where state and federal annual standards do not exist, the adopted levels are based on the extrapolation of short period standards.

Fuel Related Sources, Fuel Emissions - fuel related sources use fuel to heat area, or to raise a product to a certain temperature during an industrial process, or for cooking in the house; they produce fuel emissions. (See also Non-Fuel Related Sources.)

Fuel Use Propensity, Fuel Demand - the total heat requirement (space heating plus process heating) determines the fuel demand; the propensity to use a particular fuel or fuels determines the actual amounts of various fuels used to satisfy the heat requirement.

Heating Requirements - the demand for fuel is specified in terms of the heating requirements:

space heating - the fuel used to heat area, such as the floor space of a school in the winter, is that required for space heating; the heat content or value of that fuel defines the space heating requirement (BTUs, British Thermal Units of heating content).

non-space heating, process heating - the fuel used to raise a product to a certain temperature during an industrial process or for cooking (with gas) in the home is that required for process heating or non-space heating. It is generally not related to outside temperature whereas space heating requirements are.

percent space heating, percent process heating - the relative proportion of a fuel or its heat content that is used for space heating or process heating defines,respectively, the percent space heating or percent process heating.

Impact Measure (or Parameter) - a quantitative representation of the degree of impact on air quality or specific receptors resulting from concentrations of specified pollutants.

Influence Region - the influence region for a study area is the geographical region containing the emission sources responsible for at least 90% of the ground level concentrations (averaged throughout the study area) of all pollutants considered.

Integrated Receptor Exposure - a measure of the total impact of air quality levels on specific receptors; the measure is based on the summation within the study region of the number of receptors times the concentration levels to which they are exposed.

Inventories - the aggregation of all fuel and process emissions sources is called the emissions inventory; the components for use with the model:

current inventory - all sources for 1969

background inventory - all sources for 1990 not directly related to the meadowlands plans.

plan inventories - all sources for 1990 related to the Meadowlands plans; this excludes any source outside the Meadowlands boundary and also excludes existing major single sources and the highway network.

Isopleth - the locus of points of equal value in a multidimensional space.

Land Use Intensity - the level of activity associated with a given land use category, for example the population density of residential areas.

Land Use Mix - the percent of total study region area allocated to specific land use categories.

Meteorology - the study of atmospheric motions and phenomena.

Microscale Air Quality - the representation of air quality in a geographical scale characterized by distances between source and receptor ranging from a few meters to a few tens of meters.

Mixing Depth - the vertical distance from the ground to the base of a stable atmospheric layer (also called inversion height).

Model Calibration - the process of correlating model projections with observed (measurements) data, usually to determine calibration factors relating predicted to observed values for each pollutant.

Model Validation - the detailed investigation of model results by comparison with measured values to identify systematic discrepencies that may be conected by alterations of model parameters or model mechanics.

Non-Fuel Related Sources, Process Emissions, Separate Process Emissions - non-fuel related sources do not burn fuel primarily for heating purposes or do not burn fuel at all; these include transportation sources, incineration, and certain industrial processes; they produce process or separate process emissions. (See also Fuel Related Sources.)

Ranking Index - a quantitative representation of the net impact on air quality or specific receptors resulting from all pollutants being considered.

Receptor - a physical object which is exposed to air pollution concentrations; objects may be animate or inanimate, and may be arbitrarily defined in terms of size, numbers, and degree of specificity of the object.

Receptor Point - a geographical point at which air pollution concentrations are measured or predicted.

Regional Air Quality - the representation of air quality in a geographical scale characterized by large areas, for example, on the order of 50 square kilometers or greater.

Schedule - number of hours per year a fuel burning activity will consume fuel; used to determine heating requirements.

Source - any stationary or mobile activity which produces air pollutant emissions.

Source Geometry - all sources for modeling purposes are considered to exist as a point, line, or area, defined as follows:

point source - a single major emitter located at a point.

line source - a major highway link, denoted by its end points.

area source - a rectangular area referenced to a grid system; includes not only area-wide sources, such as residential emitters, but single emitters and highway links deemed too small to be considered individual point or line sources by the model.

Stability Category - a classification of atmospheric stability conditions based on surface wind speed, cloud cover and ceiling, supplemented by solar elevation data (latitude, time of day, and time of year).

Stability Wind Rose - a tabulation of the joint frequency of occurrences of wind speed and wind direction by atmospheric stability class at a specific location.

Total Air Quality - the air quality at a receptor point resulting from background emission sources and from emission sources specifically within the study region.

Trapping Distance - the distance downwind of a source at which vertical mixing of a plume begins to be significantly inhibited by the base of the stability layer, and gaussian vertical distribution can no longer be assumed.

Wind Sector - a 22-1/2 degree wind direction range whose center-line is one of the sixteen points of the compass.